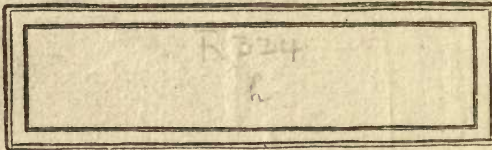
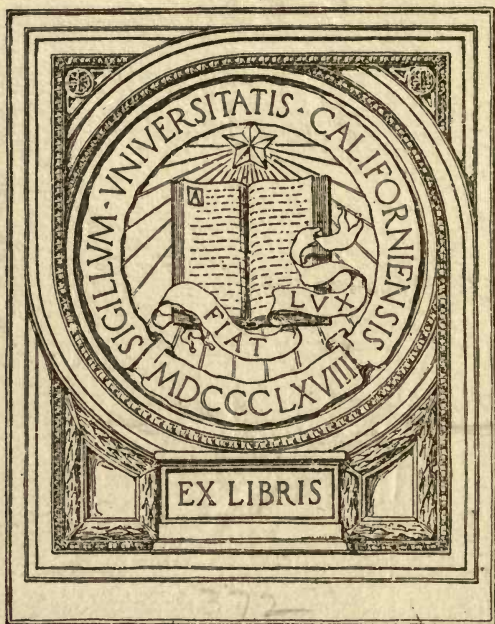
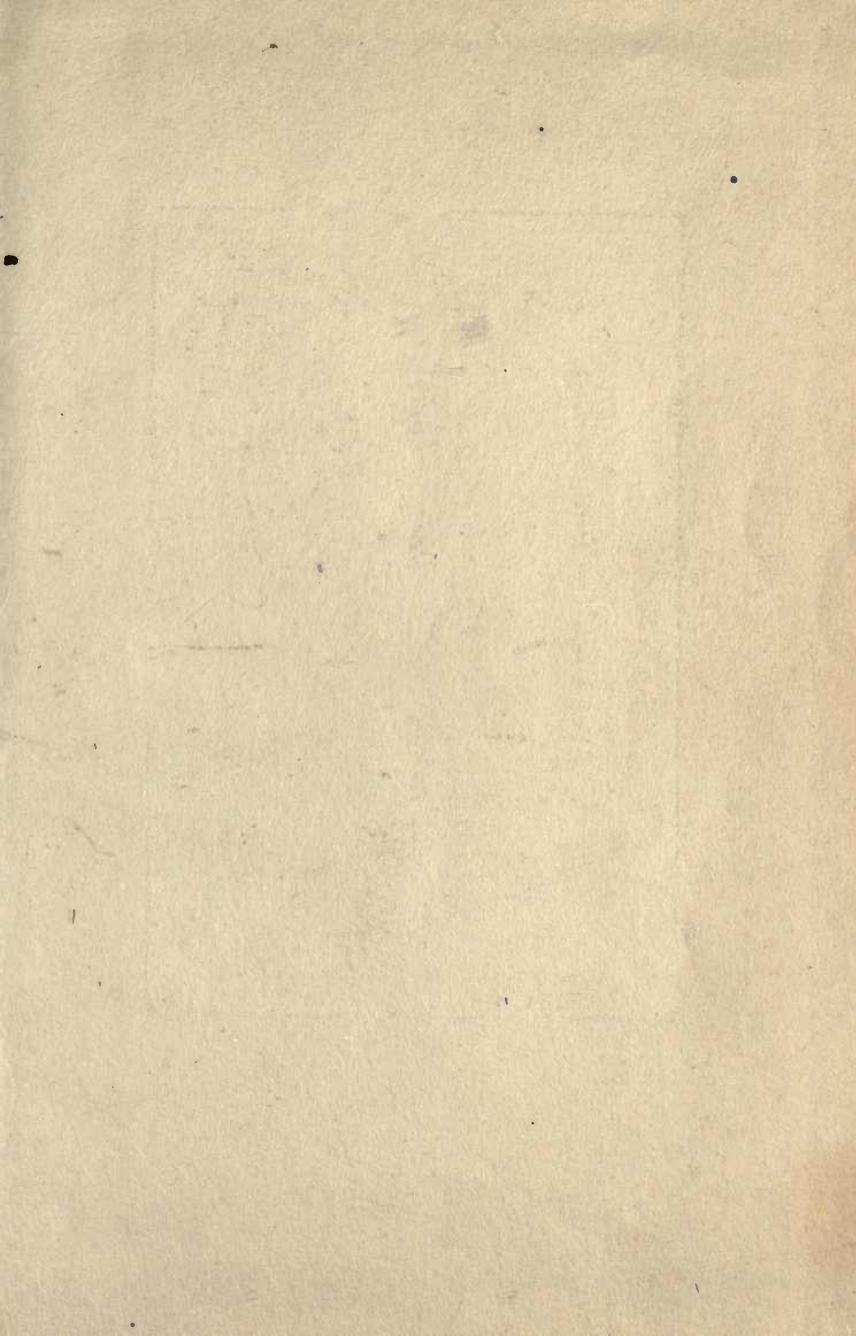
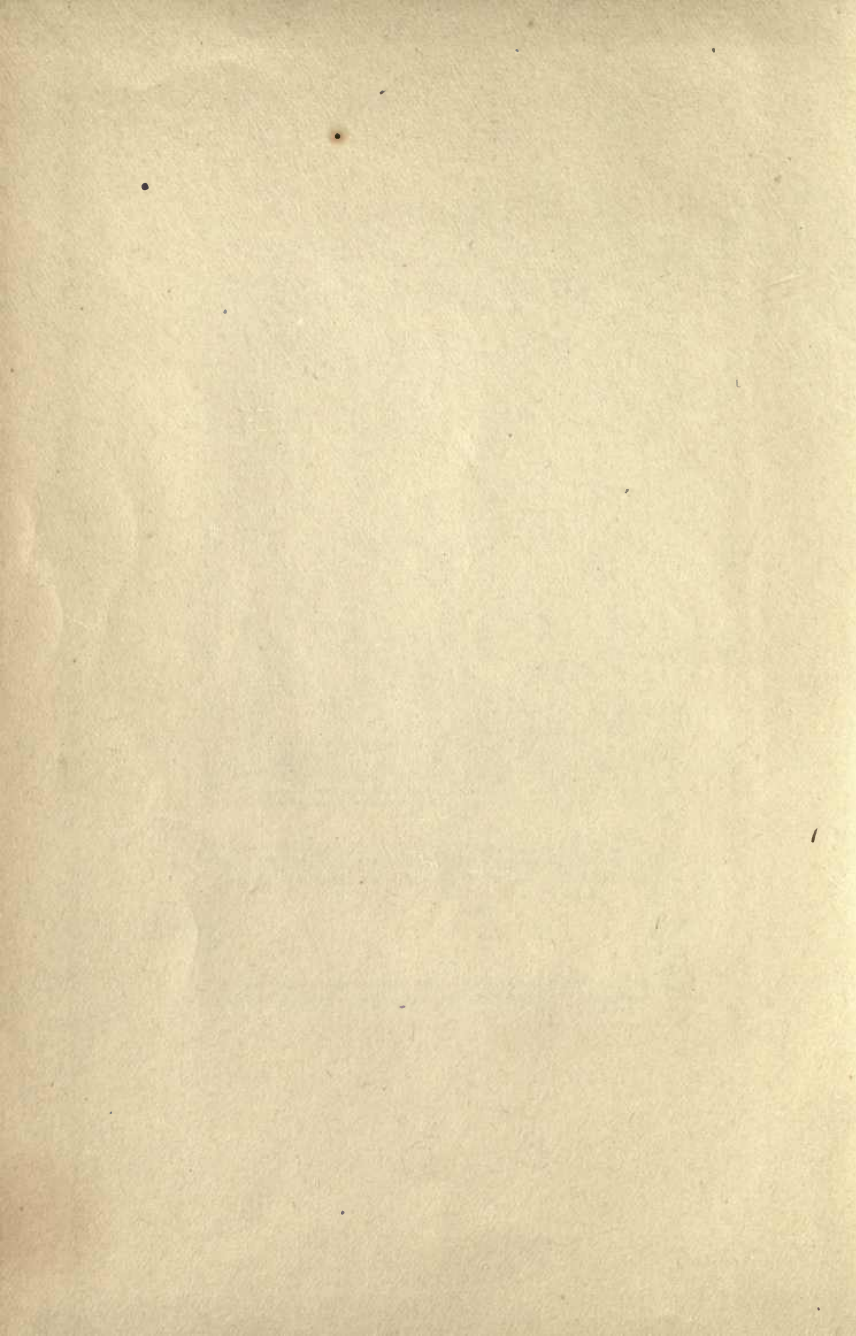


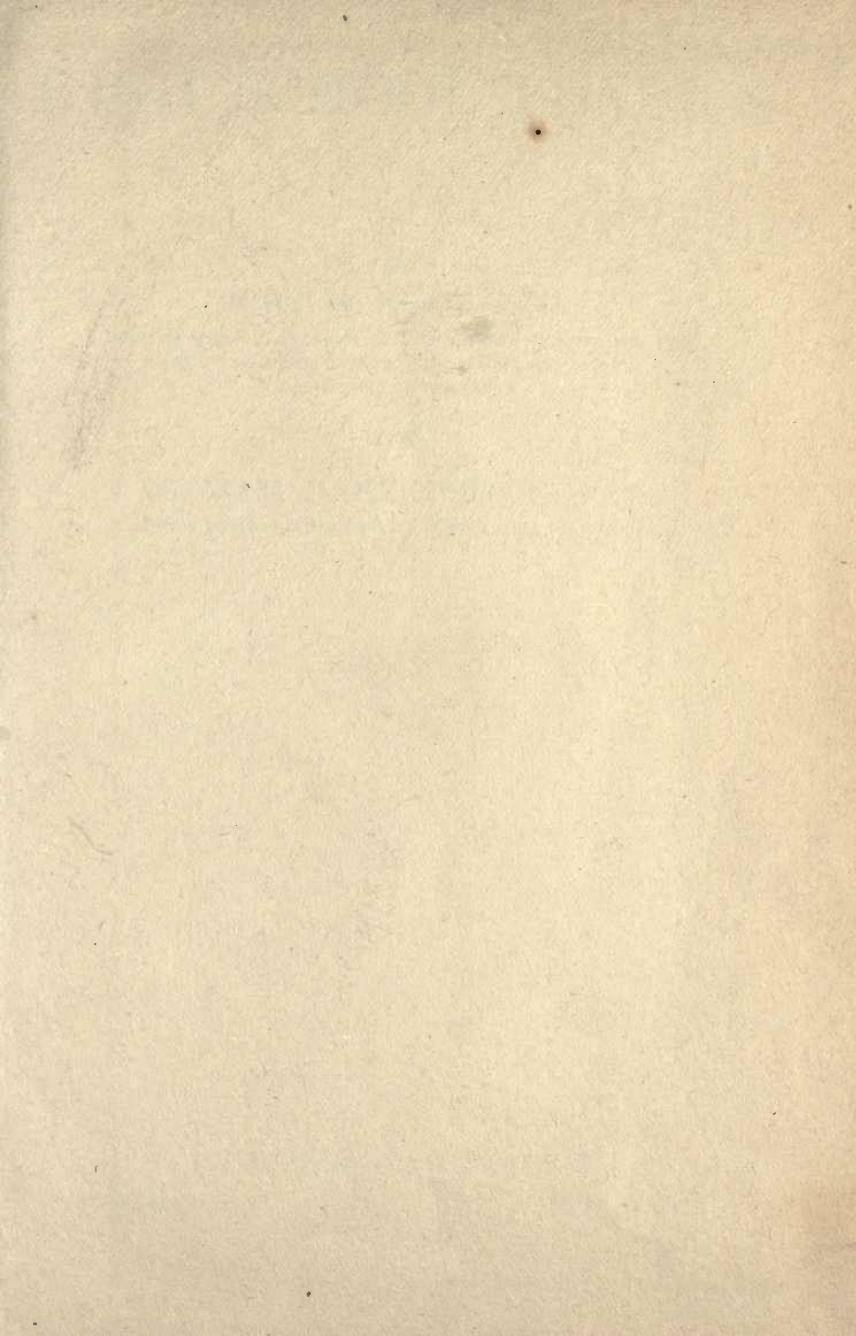
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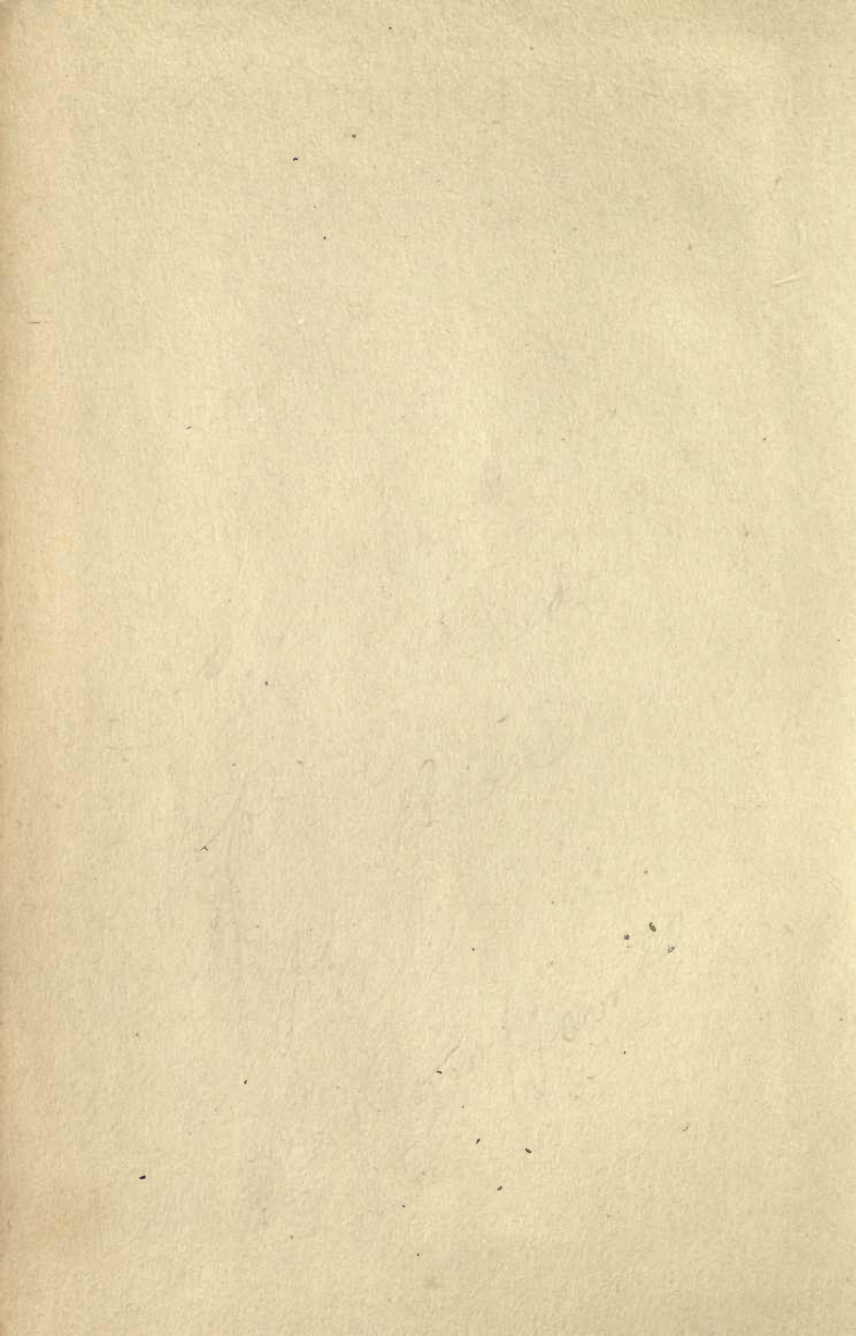
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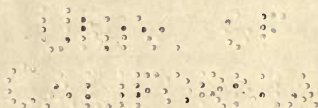
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P R E F A C E

THIS text is offered to teachers of elementary physics with the hope that it will not only prove to be teachable in method, but also that it may possess that "human touch" which will make it interesting to read as well as profitable to study.

The chief characteristics of the book are:

(a) CONTENT: The *essentials* of elementary physics.

(b) LANGUAGE: *Simple* in style and *accurate* in statement.

(c) ILLUSTRATIONS: Of the five hundred and fifty illustrations used more than *three hundred are line engravings, especially prepared to serve as part of the regular recitation work.*

(d) EXERCISES: The exercises and problems are *simple in content* and are *placed in the text in immediate connection with the topics which they were written to explain.*

(e) SUPPLEMENT: Herein is placed a large amount of supplementary material, as for example: (a) Presentation of topics of special interest to certain localities and individual students, (b) discussion of modern theories, such as the electron theory of matter, (c) biographical sketches, (d) tables of physical constants, (e) supplementary problems. *This supplementary material is classified and placed in order, where it may be made use of as occasion and opportunity demand.*

The authors desire to thank their colleagues, of the University of Michigan, Dr. Karl E. Guthe, Dean of the Graduate Department, Prof. N. H. Williams, and Mr. L. D. Rich, for a careful and critical reading of the manuscript.

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ANN ARBOR, May, 1913

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HIGH SCHOOL PHYSICS

CHAPTER I

FUNDAMENTAL PHYSICAL CONCEPTS

GENERAL PRINCIPLES

1. Definition of Physics. Science is commonly defined as classified knowledge. Botany and zoology, which deal with living things, are said to belong to the biological sciences; astronomy, physics, and chemistry, on the other hand, belong to the physical sciences. *Physics treats of the related phenomena of matter and energy; it includes the subjects of mechanics, heat, magnetism, electricity, sound, and light.*

2. Matter. Science has not yet definitely determined just what matter is, and for this reason we do not ordinarily attempt to define it in any specific manner other than to say that it possesses certain characteristic properties, such as extension, indestructibility, weight, etc. Matter, however, may be defined in a general way as anything which occupies space and has weight. Thus wood, water, and air are forms of matter, for it may be shown that all three occupy space and have weight. Electricity, heat, and light, on the other hand, are not generally considered to be forms of matter; they do not, in the ordinary sense of the term, possess weight.

3. Energy. Perhaps no two words occur more often in physics than the words energy and force, and while we shall reserve a more complete discussion of these subjects until a later chapter, yet it is necessary at the very beginning of our

study to define in a general way these most important terms. *Energy is the capacity for doing work.* Whenever anything is capable of doing work in any form whatsoever we say that it possesses energy. Thus the human body possesses energy because it is capable of doing work. Likewise the steam in an engine, the water in a mill dam, the coiled spring of a watch which has been wound, all possess energy. It should be noted that energy does not necessarily imply the doing of work, but the capacity to do work.

4. Force. Whenever we push or pull a body we exert force upon it and the body tends to move. In every act of life, therefore, forces manifest themselves. In walking, writing, rowing a boat, or pulling a sled we exert force; that is, we exert pushes or pulls. *A force always implies a push or a pull, and whenever a force acts upon a body it tends to set it in motion.*

5. The Forces of Nature. Nature is the name given to the world which we see around us — the sky, the hills, the rivers, the sunshine. We speak of the forces generated by the heat of the sun, those manifested in the waterfall, the bursting force of frost, etc., as the forces of nature. We see these forces operating everywhere about us. The hills are washed down, rocks are broken into tiny fragments, day follows night, summer follows winter. Changes due to the forces of nature are constantly going on, yet man has learned by experience that these changes do not “just happen”; they take place in a perfectly definite and orderly manner, in accordance with what are called the laws of nature.

6. Phenomenon, Theory, Law. A *natural phenomenon* is anything occurring in nature. The rising of smoke, the falling of rain, the sound of a whistle, the flying of a kite are all examples of natural phenomena.

A *theory* is a reason put forth to explain phenomena. Thus, in order to explain the motions of the heavenly bodies, we assume that every particle of matter in the universe attracts every other particle. This is called the theory of gravitation.

A *law* is a definite statement regarding physical phenomena, and is capable of being verified by experiment.

An *experiment* is a question put to nature. All experimentation is based on the assumption of the constancy of nature; we assume that under the same conditions nature always acts in the same manner.

7. Extension. *Extension* is that property of matter by virtue of which it occupies space. A fountain pen, for example, is a portion of matter. It is made of two substances, the metal of the pen and the rubber of the holder. It occupies space; it, therefore, possesses the property of extension. Air is matter. That it occupies space may be shown by a very simple experiment. If we thrust a tumbler mouth downward into water, Fig. 1, we observe that the water does not fill

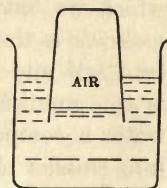


FIG. 1

it because the air within occupies a part of the space. The water rises in the tumbler a little way because the air is somewhat compressed. It is evident that the air occupies space; hence we say that air possesses the property of extension.

8. Matter Indestructible. Matter cannot be destroyed. If a piece of chalk, for example, be ground to the finest powder and thrown to the winds, we have not destroyed the chalk, but have simply changed its form. Or again, if we throw a piece of paper into the fire and it is consumed, we have not by this act destroyed a single particle of matter. We have changed both the form and the identity of the paper, but we have not destroyed the matter of which it is composed.

9. The Structure of Matter. According to present theories, matter is composed of small particles which are in constant motion. These particles, which are so small as to be invisible under the most powerful microscope, do not rest one upon another, as do bricks in a wall, but are constantly striking against each other, bounding back and forth with great rapidity. In view of this theory, the question at once arises,

How does matter retain its form? If the particles of a piece of chalk are in constant motion, how does the chalk retain its shape? The ancients supposed that the particles of which matter is composed were held together by hooks or claws; we of to-day assume that they are held together by invisible forces which allow considerable freedom of motion, yet which restrain the particles within the form of the body.

10. Molecules, Atoms, and Electrons. The particles of which we have just been speaking are called molecules. A *molecule* is the smallest particle of a substance that can exist by itself and retain its identity. Thus, a molecule of water is the smallest particle that can exist as water. A glass of water is composed of many drops; each drop may be divided into smaller and smaller parts until, it may be conceived, we come to the smallest particle that can exist as water. This is the molecule. If we carry the division further, as may be done by chemical means, we no longer have water, but two gases, hydrogen and oxygen. Molecules, then, are made up of still smaller particles called *atoms*. Thus, a molecule of water contains two atoms of hydrogen and one of oxygen.

There are many reasons which lead modern scientists to believe that atoms, in turn, may be made up of still smaller electrically charged particles called corpuscles or *electrons*. (Supplement, article 595.)

11. Chemical Symbols. The chemical symbol for a molecule of water is H_2O . This means that a molecule of water contains two atoms of hydrogen (H) and one atom of oxygen (O). A molecule of common table salt, sodium chloride, is written NaCl ; that is, the molecule is made up of one atom of sodium (Na) and one atom of chlorine (Cl). In a like manner sulphuric acid is written H_2SO_4 , where S stands for sulphur.

EXERCISE. 1. (a) How many atoms of hydrogen are contained in a molecule of sulphuric acid? (b) How many atoms of sulphur? (c) Of oxygen? (d) How many atoms in the molecule?

12. States of Matter. Matter is commonly thought of as occurring in three states — *solid*, *liquid*, and *gaseous*, as illustrated by earth, water, and air. A more specific classification, however, would assign matter to two general conditions, solid and fluid. A solid is a substance that retains both its shape and volume. A *fluid* is a substance that will flow. Fluids are divided into liquids and gases.

13. Distinction between Solids and Fluids. In everyday experience we have no difficulty in distinguishing between solids and fluids. We do not hesitate to classify the pen with which we write as a solid and the ink as a fluid. Nevertheless, in a great many cases no sharply defined dividing line can be drawn between solids and fluids. Indeed there is a continuous gradation from the most rigid solids to the rarest gases. Steel is a rigid solid; syrup is a viscous fluid. Pitch has the properties of both a solid and a fluid. If struck a sharp blow with a hammer, a lump of pitch will break like glass; if left to itself, however, it will flatten out of its own weight and will flow.

14. Physical and Chemical Changes. Matter may be changed in two ways, physically and chemically. A *physical change* is one which does not alter the identity of the substance. The tearing of a piece of paper is a physical change. The form of the paper is altered by the tearing, but not the substance; each piece is still paper. A *chemical change* is one which alters the identity of the substance. The burning of a piece of paper, for example, is a chemical change. In combustion (burning) the oxygen (O) of the air unites with the carbon (C) of the paper, forming a gas called carbon dioxide (CO_2). The chemical reaction is represented thus, $\text{C} + 2\text{O} = \text{CO}_2$.

Sometimes changes occur which are both physical and chemical, as illustrated in the chewing of a piece of bread. The crushing of the bread with the teeth is a physical change; the reaction of the saliva with the starch of the bread, changing it to sugar, is a chemical change.

EXERCISE. 2. (a) What change is involved in the breaking of a piece of chalk? (b) In the burning of a lump of coal? (c) In the melting of a piece of ice? (d) In the cooking of food? (e) In the dissolving of a metal in acid?

15. Mass. The *mass of a body* is the measure of the quantity of matter it contains. This is simply another way of saying that the mass of a body is the measure of its inertia, that is, its resistance to change in its condition of rest or motion. Thus, if two bodies of the same size, a brick and a block of wood, be acted upon by the same force, it will be found that the brick offers the greater resistance to being set in motion; that is, it possesses the greater inertia, and hence the greater mass.

16. The Force of Gravity. Daily experience teaches us that all bodies tend to fall to the earth. A piece of chalk held in the fingers is at rest; if released it at once falls to the floor. Its condition of motion is changed. Now when the motion of a body is changed, we say that a force has acted upon it. *The force by which bodies are attracted to the earth is called the force of gravity.* The apple falls from the tree to the earth because of the force of gravity; rain falls from the clouds, rivers run to the sea, bodies everywhere tend to fall because of the constant pull exerted by the force of gravity.

17. Weight. *The weight of a body is the force by which it is attracted to the earth;* weight may therefore be defined as the measure of gravity. The weight of a body depends upon two factors, (a) the quantity of matter which it contains (its mass) and (b) its position with respect to the earth. Thus, for example, for a given place on the earth's surface, a whole brick weighs more than a half brick, because the first has more mass than the second. Also, a brick at the surface of the earth weighs more than if taken some distance above the surface, because the force of gravity is greater at the surface than above it.

18. Different Uses of the Term Weight. In the study of mechanics the term weight occurs many times, and is some-

times employed in three different senses, as follows: (a) The term weight is used when referring to an object, as, for example, we may say, "Put the weight on the scale pan," meaning, thereby, a definite piece of metal; (b) it is also employed to designate a force equivalent to the attraction of gravity, as defined in the preceding topic; and (c) the word weight is frequently used as synonymous with mass. This last use of the term is confusing and misleading.

19. Distinction between Mass and Weight. It is manifestly very important that a careful distinction be made between the mass of a body and its weight. Mass refers to the quantity of matter in the body; weight, to the force with which the earth attracts the body. If an object be moved from one place to another, its mass is not affected thereby; its weight, on the other hand, may be changed, since the weight of a body is determined by the force of gravity acting upon it, and the force of gravity for a given mass differs slightly for different points upon the earth's surface.

FUNDAMENTAL UNITS OF MEASUREMENT

20. Fundamental Units. Since the study of physics includes not only the observation and classification of physical phenomena, but also the measurement of these phenomena, it is essential that we have at the very outset a clear understanding of the units employed. The fundamental units for all physical measurements are those of length, mass, and time.

The legal standards of length and mass in the United States are those of the metric system, legalized by Act of Congress in 1866. The standard of length is the meter; the standard of mass is the kilogram; the standard of time, the second.

21. The Metric Standards. The metric system was first introduced by the French about the year 1793, and has since been adopted, in whole or in part, by most of the civilized countries of the world. The meter was originally intended to be equivalent to one ten-millionth of an earth quadrant, that

is, one-fourth of a great circle of the earth; and the kilogram was intended to be equivalent to the mass of one liter of pure water. As it was found impossible, however, to determine exactly these quantities, there were arbitrarily chosen as standards a meter and kilogram which are only approximately equal to the theoretical values determined upon by the originators of the system.

The meter and kilogram which were finally chosen as standards, and which were made of platinum, are kept in the Palace of the Archives at Paris, and are known as the "Standards of the Archives."

22. The International Metric Standards. In 1872 an International Conference of Weights and Measures was called to meet at Paris. The object of this conference was to consider the question of International Standards. Thirty countries responded, the United States being among the number. At this meeting three things were accomplished: (a) An International Bureau of Weights and Measures was organized; (b) an International Laboratory, located near Paris, was established; and (c) the construction of a number of prototype standards, similar to the Standards of the Archives, was authorized. As a result of this conference a number of standard meters and kilograms were constructed of an alloy of 90 per cent platinum and 10 per cent iridium, each being as nearly as possible an exact duplicate of the Standards of the Archives. That meter and that kilogram which most closely corresponded to the meter and kilogram of the Archives were chosen as the International Standards, and were deposited in the International Laboratory, where they are now kept for reference. (Supplement, 534.) Civilized countries have entered into an agreement whereby this International Laboratory is considered neutral ground, thus avoiding, in case of war, any danger of injury to or destruction of the International Standards. The remaining standards were disposed of by lot to the various countries represented, the United States drawing two meters

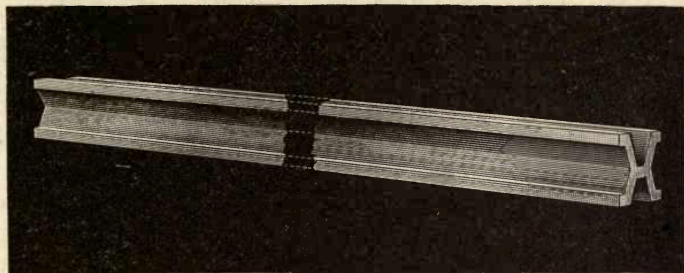


FIG. 2. — Section of U. S. Standard Meter

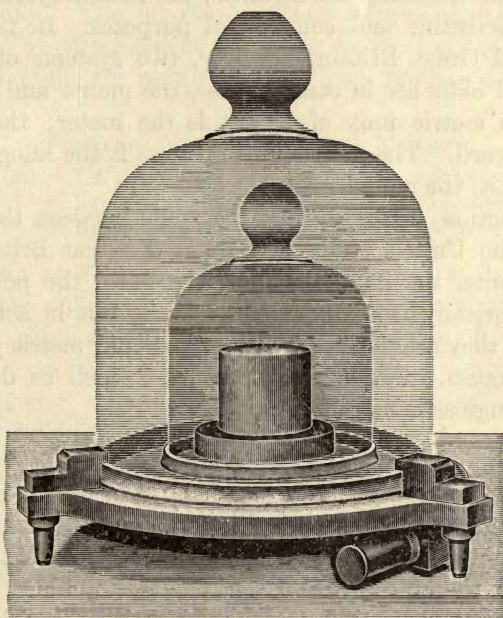


FIG. 3. — U. S. Standard Kilogram

and two kilograms—meters Nos. 21 and 27 and kilograms Nos. 4 and 20. As has already been stated, these standards were brought to this country and are now kept in the Bureau of Standards at Washington.

A very good idea of the general appearance of the U. S. standard meter and kilogram may be obtained from Figs. 2 and 3, which are copies of actual photographs. Fig. 2 shows a section of the U. S. prototype meter No. 27, and Fig. 3 kilogram No. 20. The standard kilogram is cylindrical in shape and rests upon a circular base, both being enclosed under two glass bell jars, as shown.

23. Two Systems of Measurement. In some countries, France and Germany for instance, the metric system is used both for scientific and commercial purposes. In the United States and Great Britain, however, two systems of units of length and mass are in common use, the metric and the English. The metric unit of length is the meter; the English unit, the yard. The metric unit of mass is the kilogram; the English unit, the pound.

A distinction, however, must be made between the English units of the United States and those of Great Britain. Our English units, the inch, the foot, the yard, the pound, etc., come historically from those of England, but in actual practice today they are derived from our national metric standards at Washington. For example, the U. S. inch as defined by Act of Congress is as follows:

$$1 \text{ inch (U. S.)} = \frac{1}{25.4} \text{ of 1 meter.}$$

In Great Britain, on the other hand, the inch is defined as $\frac{1}{36}$ of a standard British yard. The standard British yard and pound, together with the metric standards of that country, are kept at the office of the Exchequer in London.

The U. S. inch is slightly longer than the British inch, as shown by the following:

$$1 \text{ meter} = 39.37 \text{ U. S. inches} = 39.37079 \text{ British inches.}$$

24. Units of Length. The metric unit of length is the *meter*, which is the distance between two marks on a platinum-iridium bar kept at the Bureau of Standards at Washington.

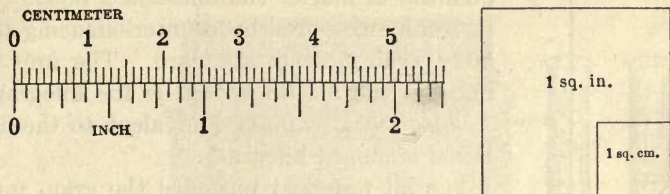


FIG. 4

The *divisions and multiples of the meter* are given in the following tables. The relation of English equivalents is shown in Fig. 4. For fractions of the meter we use the Latin prefixes deci, centi, milli; for multiples, the Greek prefixes deka, hekto, kilo.

*Fractions**Multiples*

$\frac{1}{10}$ meter (m) = 1 decimeter (dm)	10 meters = 1 dekameter (dkm)
$\frac{1}{100}$ meter = 1 centimeter (cm)	100 meters = 1 hektometer (hkm)
$\frac{1}{1000}$ meter = 1 millimeter (mm)	1000 meters = 1 kilometer (km)

25. Units of Volume. The unit of volume is the liter (l). A *liter* is the volume of one kilogram of air-free distilled water at 4° C. (Supplement, 535.) Since a kilogram of pure water, under the conditions named, has a volume of practically one cubic decimeter, a liter, therefore, may be considered as equivalent to 1000 cubic centimeters; that is,

$$1 \text{ liter} = 1000 \text{ cc.} = 1.0576 \text{ qts. (liquid measure).}$$

EXERCISES. 3. Determine the length and width of the laboratory table in (a) metric units; (b) English units.

4. Draw on paper (a) a square centimeter; (b) square inch; (c) square decimeter.

5. Give the equivalents of the following abbreviations: m., cm., mm., km., in., ft., sq. cm., cu. cm.

6. Pour a quart of water into a liter measure and observe how nearly a liter equals a quart in volume.

7. Find the volume of a piece of metal or stone by means of a graduate, as shown in Fig. 5.

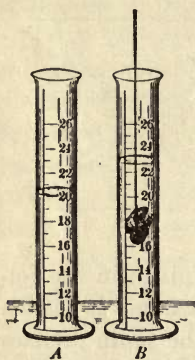


FIG. 5

26. Units of Mass. We have already defined mass as the quantity of matter contained in a body. It is usually measured by counterbalancing the body against some standard. The unit of mass in the metric system is the kilogram. A *kilogram* is a mass equivalent to the national standard kilogram.

For all practical purposes the gram may be considered as equivalent to the mass of a cubic centimeter of distilled water at 4°C . It must be remembered, however, that this is only approximately true, a gram being, by exact definition, $\frac{1}{1000}$ of a standard mass known as the standard kilogram.

The divisions of the kilogram and gram, together with equivalents in the English system, are as follows:

1 gram = $\frac{1}{1000}$ kilogram (k)	1 gram = 15.432 grains; that is,
$\frac{1}{10}$ gram = 1 decigram	1 grain = $\frac{1}{15.432}$ gram
$\frac{1}{100}$ gram = 1 centigram	1 kilogram = 2.2046 pounds (Av.)
$\frac{1}{1000}$ gram = 1 milligram (mg)	

27. The Balance. In accurate determinations of mass we ordinarily use some form of the balance. In Fig. 6 there is shown one type of the analytic balance, and in Fig. 7 a set of standard weights, ranging in value from 100 grams to 1 gram. To determine the mass of a body by means of a balance we proceed somewhat as follows: The given body is placed on one of the scale pans of the balance and standard weights are added to the other pan until the balance is in equilibrium. The mass of the body is equal to the mass of the weights required to counterbalance it.

28. Unit of Time. The unit of time is the second. A *second* is $\frac{1}{86400}$ of a mean solar day. A solar day is measured from sun to sun; that is, from the time the sun is directly

overhead until it is in the same position again on the following day. Solar days, however, vary in length throughout the year; it is necessary, therefore, to define the second in terms

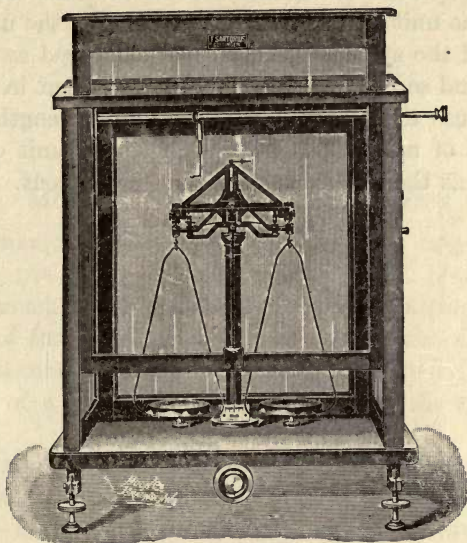


FIG. 6. — Analytical Balance

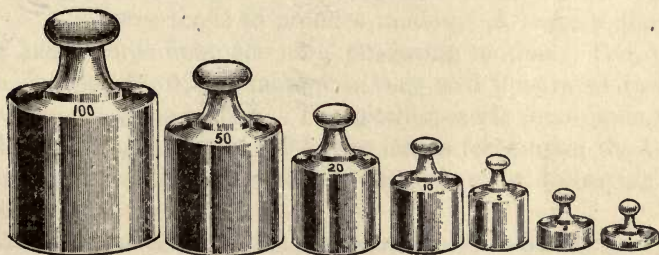


FIG. 7. — Set of Standard Gram Weights

of the mean solar day. A *mean solar day* is the average length of all the solar days taken throughout the year.

The time recorded by clocks and watches is expressed in mean solar time.

29. F.P.S. and C.G.S. Systems of Measurement. When in the English system we use the foot as the unit of length, the pound as the unit of mass, and the second as the unit of time, we speak of the system of units thus employed as the F.P.S., or foot-pound-second, system. Likewise, when in the metric system we use the centimeter as the unit of length, the gram as the unit of mass, and the second as the unit of time, we speak of it as the C.G.S. system of measurement.

MECHANICS

CHAPTER II

FORCE AND MOTION

MOTION, VELOCITY, ACCELERATION

30. Mechanics. The term mechanics, as originally used, referred to the study of machines. It has, however, come to have a much wider meaning, referring in a general way to the effect of forces on bodies. The force exerted by a locomotive, that exerted in the batting of a ball, the flying of a kite, the sailing of a boat, are all illustrations of the principles of mechanics.

31. Force. When we push or pull a body we exert force upon it, and the body tends to move. *Force is that which produces or tends to produce motion.* Force always produces or tends to produce motion. A book lying on a table exerts a force upon the table. In this case no motion is produced; the force tends to produce motion. A horse pulling a cart exerts force upon the cart, producing motion. The relation between force and motion is very well illustrated in the playing of a game of ball. The pitcher exerts force upon the ball, producing motion; the batter exerts force upon the ball, changing its motion; the catcher exerts force in destroying its motion.

32. Rest and Motion Relative Terms. When a body changes its position with reference to a fixed point, it is said to be in motion. Rest and motion are purely relative terms; that is to say, a body may be at rest with reference to one object, and in motion with reference to another. For example, a person

sitting quietly in a moving car is at rest with respect to his seat, but is in motion with respect to objects outside.

EXERCISES. 1. (a) If the hand be clinched and moved about, are the fingers at rest or in motion with reference to each other? (b) Are they at rest or in motion with reference to the body?

2. Consider the wheel of a carriage in motion. (a) Are the spokes at rest or in motion with respect to each other? (b) Are they at rest or in motion with respect to the earth?

3. Give another example of a body that is at rest in its relation to one object and in motion in relation to another.

33. Kinds of Motion. Motion may be classified with reference to direction as (a) rectilinear or straight-line motion, and (b) curvilinear or curved-line motion. Motion may also be classified with reference to rate as (a) uniform motion, and (b) varied motion. When a body travels over equal spaces in equal intervals of time, its motion is uniform; when it travels over unequal spaces in equal intervals of time, its motion is varied. There is probably no such thing in the universe as an example of absolutely uniform motion, since all bodies in moving change in some degree their rate. We can, however, imagine such a thing as uniform motion, or we may find examples of motion which are approximately uniform.

EXERCISE. 4. Classify, with reference to direction and rate, the following motions: (a) The piston of a steam engine; (b) the hands of a clock; (c) the flywheel of an engine; (d) the rotation of the earth on its axis.

34. Velocity. *Velocity is the rate of motion per unit of time.* It is usually expressed in miles per hour, feet per second, or centimeters per second. The term velocity, when used in a strictly scientific sense, refers to the rate of motion of a body in a definite direction; *speed*, on the other hand, refers to the rate of motion without reference to direction. Thus, when we speak of the speed of a race horse, we refer to its rate of motion only, without reference to any particular direction.

The mean or average velocity of a body is found by dividing the space passed over by the time.

EXERCISE. 5. If a train run 120 miles in 4 hours, what will be its average velocity in (a) miles per hour? (b) feet per hour? (c) feet per second?

35. Acceleration. When the velocity of a body increases or decreases, its motion is said to be accelerated. *Acceleration is the change of velocity per unit of time.* If there is an increase of velocity per unit of time, the acceleration is called positive; if a decrease, negative. The symbol for positive acceleration is $+a$; for negative, $-a$. Velocity is expressed in units per second; acceleration, in units per second per second. Thus, when we say that a body has an acceleration of 10 centimeters per second per second, we mean that its velocity has increased or decreased by 10 centimeters per second in one second.

EXERCISES. 6. A sled starting from rest runs down hill. Its initial velocity is 0; its velocity at the end of the 1st second is 6 ft. per second; at the end of the 2d second, 12 ft. per second; at the end of the 3d second, 18 ft. and so on. (a) What is the increase in velocity per second? (b) The positive acceleration?

7. A stone is thrown upward with an initial velocity of 2940 cm. per second. Its velocity at the end of the 1st second is 1960 cm. per second; at the end of the 2d second, 980 cm. per second, and so on. (a) What is the decrease in velocity per second? (b) The negative acceleration? (c) How long will it continue to rise? (d) In how many seconds after leaving the hand will it strike the ground?

8. A ball rolling down an incline makes a gain in velocity of 20 cm. in 4 seconds. What is the acceleration?

36. Illustrations of Accelerated Motion. Let us consider the case of a marble starting from rest and rolling down an inclined plane, Fig. 8. Suppose that the incline have a pitch such that the marble acquires at the end of the 1st second a velocity of 2 feet per second. That is, starting from rest, its velocity at the end of the 1st second is 2 feet per second; the velocity at the end of the 2d second will be 4 feet per second; at the end of the 3d second, 6 feet, and so on. The following points with respect to the motion of the marble may be noted:

First, since the body is acted upon by a constant force (the force of gravity) its motion down the incline is uniformly accelerated, the gain in velocity (acceleration) being 2 feet per second per second.

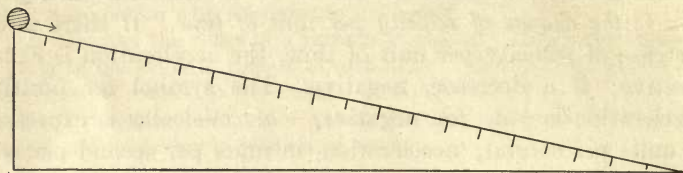


FIG. 8

Second, the average velocity for any interval or number of intervals may be determined by taking one-half the sum of the velocity at the beginning and at the end of the interval; that is,

$$\text{average velocity} = \frac{\text{velocity at beginning} + \text{velocity at end}}{2}$$

Thus, the average velocity for the 1st second is $\frac{0 + 2}{2} = 1$ foot per second; for the 2d second, $\frac{2 + 4}{2} = 3$; for the 3d second, $\frac{4 + 6}{2} = 5$, etc. In a like manner we may find the average velocity for any number of seconds, as, for example, the first 3 seconds, thus, $\frac{0 + 6}{2} = 3$ feet per second.

Third, the space passed over during any interval or number of intervals is equal to the average velocity multiplied by the time. Thus, for the 1st second the average velocity is 1 foot per second and the time 1 second, therefore, the space passed over during this second is 1 foot; for the 2d second the average velocity is 3 and the time 1, hence the space passed over is 3 feet; for the 3d second the average velocity is 5, and hence the space passed over is 5 feet. Likewise, since the average velocity for the first 3 seconds is 3 feet per second, and the time is 3, the total space passed over during this interval is 9 feet, and so on for any interval we may choose.

The above facts may be given in tabular form as in the following outline:

<i>Time</i>	<i>Velocity</i>	<i>Space per second</i>	<i>Total space passed over</i>
Beginning of time	$V_0 = 0$	0	0
End of 1st second	$V_1 = 2$	1	1
“ 2d “	$V_2 = 4$	3	4
“ 3d “	$V_3 = 6$	5	9
“ 4th “	$V_4 = ?$?	?
“ 5th “	$V_5 = ?$?	?
“ 10th “	$V_{10} = ?$?	?

EXERCISES. 9. What is the acceleration of the marble? Is it positive or negative?

10. What is the velocity at the end of the 4th second? The 5th second? The 10th second?

11. What is the average velocity during the 4th second? The 5th second? The 10th second?

12. What is the average velocity during the first 4 seconds? The first 5 seconds? The first 10 seconds?

13. What is the space passed over during the 4th second? The 5th second? The 10th second?

14. What is the space passed over during the first 4 seconds? The first 5 seconds? The first 10 seconds?

15. What is the average velocity for the interval (3 seconds) included between the end of the 1st second and the end of the 4th second? What space is passed over during this interval?

37. Summary. The facts brought out in the preceding topic with reference to the accelerated motion of a body starting from rest may conveniently be summarized in the following manner. It is evident that the velocity of a body having uniformly accelerated motion may be determined at the end of any interval by simply adding the acceleration to the velocity at the end of the preceding interval. Since, however, the acceleration is constant, the most convenient way of finding the velocity at the end of any interval is to multiply the acceleration by the time; that is,

$$\begin{aligned} \text{velocity} &= \text{acceleration} \times \text{time} \\ v &= at \end{aligned}$$

If now, we desire to compute the space passed over by a body starting from rest, that is, having an initial velocity equal to 0, and having a velocity at the end of t seconds equal to at , we may write

$$\text{average velocity} = \frac{0 + at}{2}$$

Since the space passed over is equal to the average velocity multiplied by the time, we may therefore write

$$\begin{aligned} \text{space} &= \text{average velocity} \times \text{time} \\ s &= \left(\frac{0 + at}{2} \right) \times t, \text{ that is,} \\ s &= \frac{1}{2} at^2 \end{aligned}$$



FIG. 9

For a discussion of the motion of bodies which do not start from rest but which have an initial velocity, see Supplement, 536.

38. Falling Bodies. Whenever a force acts upon a body it always tends to produce motion. A stone dropped from the hand falls to the earth with an accelerated motion due to the force of gravity. If it were not for the friction of the air all bodies would fall with equal velocities. If a feather and a coin, for example, be dropped from a given height, it will be observed that the coin will reach the ground first. If, however, the feather and coin be placed in a tube, Fig. 9, and the air be exhausted by means of an air pump, it will be found that both fall with the same velocity, showing that in a vacuum bodies fall with equal velocities. The acceleration imparted to a freely falling body by the force of gravity

is represented by the symbol g . The numerical value of this acceleration due to gravity is approximately as follows:

$$g = 32 \text{ ft. per sec. per sec.} = 980 \text{ cm. per sec. per sec.}$$

This means that if a body start from rest and fall freely under the influence of gravity it will have at the end of the 1st second a velocity of 32 feet per second; at the end of the 2d second, 64 feet per second; at the end of the 3d second, 96 feet per second, and so on: or if this be expressed in metric units, its velocity at the end of the 1st second will be 980 centimeters per second; at the end of the 2d second, 1960 centimeters per second, and so on.

The student must bear in mind that the values of g given above are those which are usually used in making calculations involving the acceleration due to gravity. Since the force with which the earth attracts bodies differs slightly from place to place, it follows that the value of g will be somewhat different for different places, as explained in Art. 82.

Falling bodies are subject to the laws of accelerated motion. The equations for falling bodies starting from rest are similar to those already discussed in Art. 37.

$$v = gt$$

$$s = \frac{1}{2} gt^2$$

EXERCISES. 16. Suppose that a sled start from rest on a hillside and move downward with an acceleration of 3 ft. per second. (a) What will be its velocity at the end of 10 seconds? (b) At the end of 1 minute?

17. (a) Over what space will the sled pass during the 10 seconds? (b) During the first minute?

18. A body starting from rest falls for 10 seconds. Find its velocity at the end of this time in (a) feet per second; (b) centimeters per second.

19. How far will the body fall during the 10 seconds in (a) feet? (b) centimeters?

NEWTON'S LAWS OF MOTION

39. Laws of Motion. The relation between force and motion is expressed by three important laws known as Newton's laws of motion. These laws were formulated by Sir Isaac Newton (1642-1727), a famous English mathematician and physicist, and upon them is based some of the most important principles of modern mechanics. The three laws of motion are as follows:

I. *Every body tends to preserve its state of rest or of uniform motion in a straight line unless compelled by some external force to change that state.*

II. *Change of motion is proportional to the impressed force, and takes place in the direction in which the force acts.*

III. *To every action there is an equal and opposite reaction.*

40. Inertia. Newton's first law of motion is sometimes called the law of inertia. *Inertia is that property of matter by virtue of which a body at rest tends to remain at rest, and when in motion tends to continue in motion in a straight line.* Inertia is the inability of a body, of itself, to change its state of rest or motion. A book lying on a table will, by virtue of its inertia, lie there forever unless acted upon by some external force; likewise, a stone thrown upward will, by virtue of its inertia, move out into space in a straight line if not acted upon by some outside force, as for example, the force of gravity.

41. Illustrations of Inertia. *Experiment.* Place a coin upon a card resting on the end of a rod clamped to the table, Fig. 10. If the card be snapped sharply with the finger, it will fly out, leaving the coin in place on the end of the rod. The coin remains stationary because of its inertia. Other illustrations are seen in the jerking of a sled from beneath a child sitting upon it; the forward motion of a person in a car when it suddenly comes to rest; the hammering of water in water pipes when the faucet is suddenly closed; the stamping of snow

from the feet. An interesting illustration of inertia is that of the motion of a circus rider in jumping over a line as shown in Fig. 11. All the rider has to do in order to perform his act is



FIG. 10

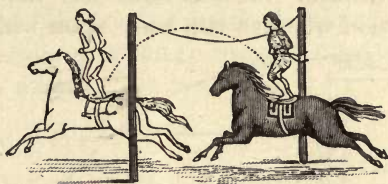


FIG. 11

to jump high enough to clear the line, the inertia of his body carrying him forward so that he lands again squarely upon the horse.

42. Momentum. The second law of motion may be called the law of momentum. *Momentum is the quantity of motion which a moving body possesses.*

$$\text{Momentum} = \text{mass} \times \text{velocity} = mv.$$

There is no generally accepted name given to the unit of momentum. (Supplement, 537.) We may say, for example, that the momentum of a mass of 10 pounds moving with a velocity of 10 feet per second is $10 \times 10 = 100$. Also, the momentum of a mass of 10 tons moving with a velocity of 10 yards per second is $10 \times 10 = 100$. If, however, we wish to compare the momenta of the two bodies, it is necessary to reduce the factors of mass and velocity to some common unit. Thus, in the case given above, the momentum of the first body, in terms of pounds and feet, is $10 \times 10 = 100$; the momentum of the second body, expressed in the same units, is $20,000 \times 30 = 600,000$. The momentum of a body may be changed by changing its mass or velocity, or both.

43. Further Illustrations of the Second Law of Motion. An interesting illustration of the second law of motion is that seen

in the effect of the force of gravity on a projectile, as shown in Fig. 12. Suppose that a ball is fired horizontally from a cannon, and at the same instant a similar ball is dropped vertically downward. Since a force has the same effect in producing motion whether the body upon which it acts is at rest or in

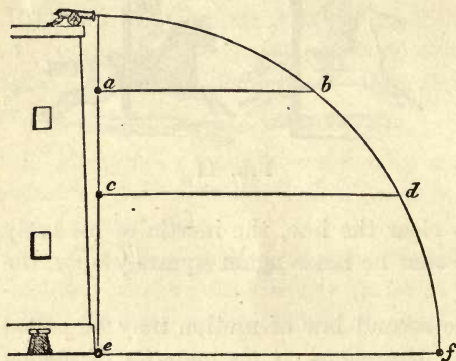


FIG. 12

motion, or whether the body is acted upon by that force alone or by other forces at the same time, it follows that both balls will reach the ground simultaneously.

44. Action and Reaction. The third law of motion states that to every action there is an equal and oppo-

site reaction; that is, *every force is two sided in its nature*. If we push on a wall with a given force, the wall reacts (pushes back) with an equal force. In rowing a boat we act on the water, and the water in turn reacts on the boat, causing it to move. The bird in flying acts on the air with its wings; the air reacts on the bird, giving it motion.

An excellent illustration of action and reaction is that seen in the case of the rotating lawn sprinkler. The water in flowing from the sprinkler, Fig. 13, reacts upon the curved arms, causing them to rotate. The action of the sprinkler is exactly similar to that which occurs when a person attempts to jump from a light boat to the shore. As the person jumps forward (action) he kicks the boat backward (reaction).

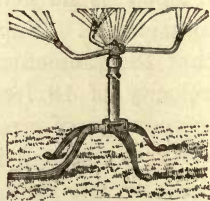


FIG. 13

EXERCISE. 20. Would a rotating lawn sprinkler work in a vacuum?

45. Relation of Action and Reaction to Momentum. The terms action and reaction may be interpreted to mean momentum. (Supplement, 538.) For example, when the powder in a gun explodes it acts upon both the bullet and the gun with equal force. The momentum of the gun is equal to the momentum of the bullet. This relation of action to reaction may be expressed by an equation as follows:

$$mv = m'v'$$

in which m and v equal the mass and velocity of the gun, and m' and v' the mass and velocity of the bullet. The velocity of the bullet will be as many times greater than the velocity of the gun as the mass of the gun is greater than the mass of the bullet. The lighter the gun, therefore, the greater its "kick" or recoil. If bullet and gun were of equal masses they would fly apart, when the powder explodes, with equal velocities.

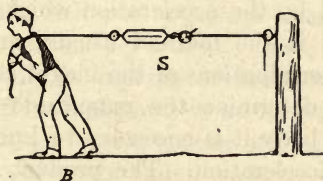


FIG. 14

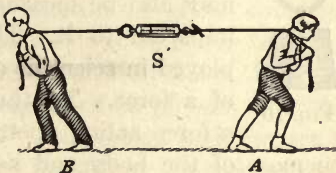


FIG. 15

EXERCISES. 21. Suppose that a ball of mass 1 lb. is fired from a cannon of mass 1 ton, with a velocity of 1000 ft. per second. What will be the velocity of the gun's recoil?

22. When an apple falls to the earth its momentum toward the earth, according to the third law of motion, is equal to the momentum of the earth toward the apple. How does the velocity of the earth compare with that of the apple?

23. A boy pulls on a rope, as shown in Fig. 14, with a force of 50 lbs., as registered by the spring balance S . (a) What force is exerted on the rope? (b) What force is exerted on the post?

24. If a second boy take the place of the post, Fig. 15, and each pull with a force of 50 lbs., what will be the reading of the spring balance?

UNITS OF FORCE

46. Force Measured by a Spring Balance. One of the most usual methods of measuring the pull which a force exerts is by means of the spring balance, or dynamometer as it is sometimes called, Fig. 16.



FIG. 16

Experiment. Attach to the hook of a spring balance a given mass. The pointer of the instrument moves to a certain position on the scale. This indicates, in pounds or grams as the case may be, the force with which the earth attracts the body. Now, attach the hook of the balance to some object, say a nail or a hook in the wall, and pull upon it. The reading of the instrument again indicates the magnitude of the force exerted.

47. Force Measured by the Product of Mass and Acceleration. The force exerted upon a given mass may also be measured by the acceleration which is imparted to it. This is the method usually employed in scientific determinations of the magnitude of a force. To thus determine the magnitude of a force acting upon a body it is necessary to know the mass of the body and its acceleration. The product of these two factors is a measure of the force; that is, $F = ma$.

48. Units of Force. The units employed in this country are of two kinds: (a) the gravitational units and (b) the absolute units, each being measured in terms of both the English and the metric systems. The gravitational units are used in nearly all ordinary practical measurements; the absolute, in accurate scientific measurements. The following outline may be of service in making clear the relation of the two sets of units.

Units of force	{	gravitational	{ pounds of force
			{ grams of force
	{	absolute	{ poundals
			{ dynes

49. Gravitational Units of Force. *The gravitational units of force are those which compare the push or the pull exerted by a force with the attraction due to gravity. The English gravitational unit is the weight of a pound (also called the force of a pound). The weight of a pound is a force equivalent to the attraction of the earth for a pound of mass. (Supplement, 539.) The force of a gram (weight of a gram) is a force equivalent to the attraction of the earth for a gram mass. Since the attraction of the earth for a given mass varies slightly for different places, the gravitational units of force likewise vary. This variation for ordinary practical measurements, however, is so small as to be negligible.*

50. Absolute Units of Force. The absolute units of force, the poundal and the dyne, are derived from the product of the mass of a body and the acceleration imparted to it. *The poundal is that force which will give to a pound mass an acceleration of one foot per second per second. The dyne is that force which will give to a gram mass an acceleration of one centimeter per second per second.* Since the absolute units are used primarily in making accurate scientific measurements, it is not highly important, in an elementary work on physics, that this subject receive special attention. Two things with respect to the absolute units, however, are important for the student to keep in mind; namely, (a) that in accurate scientific measurements the absolute units *are* used, and (b) that from the absolute units there are derived some of our most common practical units, such as the watt and the kilowatt.

51. The Relation of Absolute to Gravitational Units. The relation of gravitational to absolute units (Supplement, 540) may be expressed, approximately, as follows:

$$1 \text{ pound of force} = 32 \text{ poundals}$$

$$1 \text{ gram of force} = 980 \text{ dynes}$$

EXERCISES. 25. A mass of 10 grams held in the hand exerts upon the hand, due to the attraction of the earth, a force of 10 grams. What is the force in dynes?

26. A mass of 1 kilogram rests upon the table. What force does it exert upon the table in (a) grams of force? (b) dynes?

27. A magnet exerts a force of 6860 dynes on a piece of iron. Find the force in grams.

COMPOSITION AND RESOLUTION OF FORCES

52. Graphic Representation of Forces. A force is fully described when we know three things about it; namely, (a) its point of application, (b) its magnitude, and (c) its direction. (Supplement, 541.) Thus, when we say, "A force of 10 pounds acts vertically downward on a body," we fully describe the force, because we designate its point of application, its magnitude (10 lbs.), and its direction (downward).

Forces, velocities, and accelerations may be represented graphically by means of lines. Thus, the line AB , Fig. 17,

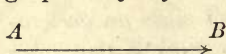


FIG. 17.

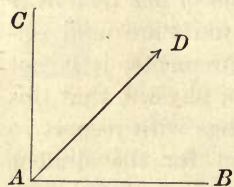


FIG. 18

represents a force acting from A to B . If we let a length of one inch represent a force of 10 pounds, then a line 6 inches in length will represent a force of 60 pounds. Likewise, a velocity of 20 miles per hour in a northeasterly direction may be represented in magnitude and direction by a line 20 centimeters in length drawn from A to D , as shown in Fig. 18. When drawing upon the blackboard, the inch may conveniently be used as the scale unit; when drawing upon paper, the centimeter, or in some cases the millimeter, is the unit usually employed.

53. Composition of Forces. If two or more forces act upon a body at the same time the resultant force may be determined graphically. The various forces acting upon a body are called *components*; a single force which acting alone will produce the same result as the components is called the *resultant*. The process of finding the resultant of a number of forces is called the *composition of forces*. We may in a like manner speak of

the composition of velocities and accelerations. In the composition of forces, velocities, and accelerations there are a number of important cases which are considered in an elementary manner in the following topics.

54. Parallel Forces in the Same Straight Line. The resultant of two or more forces acting in the same straight line is equal to the algebraic sum of the forces. Components acting to the right or upward from a given point are said to have the plus sign; those acting downward, or to the left, the minus sign.

EXERCISES. 28. If a man on top of a freight car, which moves with a velocity of 30 ft. per second, run in the direction in which the car is moving, with a velocity of 10 ft. per second, what is the resultant (actual) velocity of the man?

29. Suppose that the man run in the opposite direction with a velocity of 10 ft. per second. What will be the resultant velocity?

30. Three forces, one due to the tide, one due to the wind, and the third the force exerted by the engine, act in the same straight line upon a boat. The tide acts to the westward with a force of 4 units; the wind acts in the same direction with a force of 12 units; the engine drives the boat to the eastward with a force of 50 units. Find the magnitude and direction of the resultant.

55. Parallel Forces not in the Same Straight Line. The resultant of two forces acting in the same direction but not in the same straight line is equal to the sum of the forces, and the point of application of the resultant divides the distance between the forces into lengths inversely proportional to the forces.

Experiment. This principle may be illustrated by means of two spring balances and a weight, Fig. 19. Let a given weight W (12 lbs., for example) be suspended at such a point B that the force on the spring balance S is 4 pounds

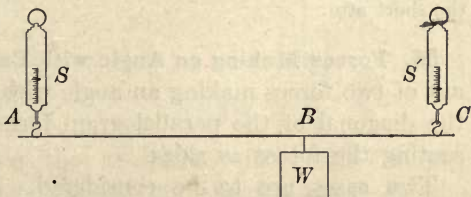


FIG. 19

and the force on S' 8 pounds. The resultant W equals $4 + 8 = 12$. The relation of the two arms AB and BC may be expressed:

$$AB : BC = 8 : 4$$

It is important to note that the greater force (8) is on the side of the short arm, and the lesser force (4) is on the side of the long arm.

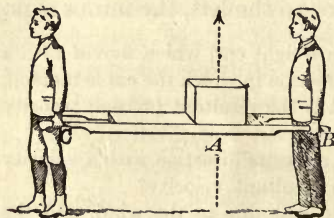


FIG. 20

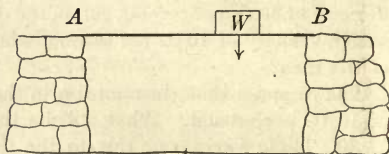


FIG. 21

EXERCISES. 31. If W , Fig. 19, exert a force of 20 lbs., what will be the force on S and on S' if W be placed (a) midway between A and C ? (b) $\frac{1}{2}$ of the distance from A ? (c) $\frac{1}{2}$ of the distance from C ?

32. Two boys, Fig. 20, carry between them a block of ice weighing 90 lbs. The distance AB is 2 ft. and the distance AC is 4 ft. Find what part of the load each boy carries.

33. A mass of 600 lbs. rests on a beam AB , 9 ft. in length, Fig. 21, at a distance 3 ft. from B . How much does each support carry, neglecting the weight of the beam?

34. If AC , Fig. 19, be 100 cm. in length, where must a weight of 300 grams be placed so that the force exerted on S shall be 75 grams and on S' 225 grams. Note.—Let x equal the long arm AB and $(100 - x)$ equal the short arm.

56. Forces Making an Angle with Each Other. The resultant of two forces making an angle with each other is equal to the diagonal of the parallelogram formed by the lines representing the forces as sides.

Two cases are to be considered. *First*, when the angle formed by the components is a right angle, Fig. 22, and *sec-*

ond, when the angle formed by the components is not a right angle, Fig. 23. In the first case the resultant R is the hypotenuse of a right angled triangle, and we may write $R = \sqrt{AB^2 + AC^2}$. In the second case three methods of find-

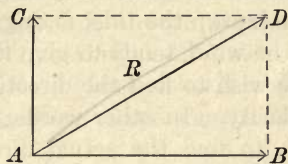


FIG. 22

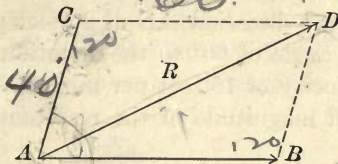


FIG. 23.

ing the resultant are possible: (a) By experiment with spring balances; (b) by the graphic method; and (c) by the use of trigonometry. In elementary texts only the first two methods are, in general, employed.

57. Experimental Determination of the Resultant. *Experi-*

ment. Suspend two spring balances C and D from hooks in the frame of the black-board, and attach to them a weight W , Fig. 24. Lay off on the board the line Ac equal in inches to the numerical reading of the balance C ; lay off another line Ad numerically equal in inches to the reading of the balance D . Now complete the parallelogram, and the diagonal AB will represent in di-

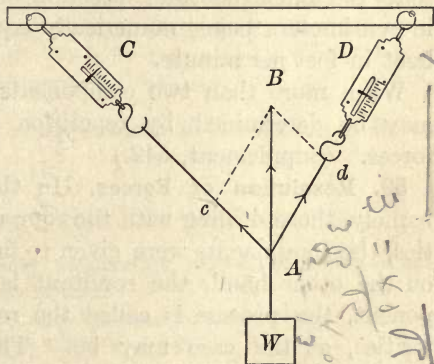
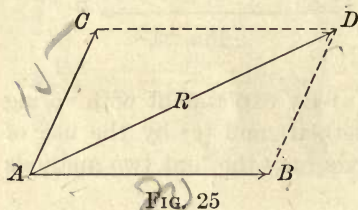


FIG. 24

rection and magnitude the resultant. The value of this resultant in inches should be numerically equal to the weight W .

58. Graphic Method of Finding the Resultant. To find the resultant of two components which act upon a body at a given angle. Suppose that A represents a boat on the surface of the lake, and that it is acted upon by two forces, the wind and the tide. The wind tends to give it a velocity in the direction AB of 20 feet per minute; the tide, acting at an angle of 60° to the direction of the wind, tends to give it a velocity of 15 feet per minute. We wish to find the direction and magnitude of the resultant velocity. In other words, we



wish to find the actual direction and velocity of the boat. Lay off on paper a line AB 20 centimeters in length to represent a velocity of 20 feet. From the point A , Fig. 25, lay off AC 15 centimeters in length, making with AB an angle of

60° . Now complete the parallelogram. The line AD represents the magnitude and direction of the resultant, its length in centimeters being numerically equal to the velocity of the boat in feet per minute.

When more than two components are given, the resultant may be determined by repetition of the parallelogram of forces. (Supplement, 542.)

59. Resolution of Forces. In the cases just considered, namely, those dealing with the composition of forces or velocities, the components were given to find the resultant. When, on the other hand, the resultant is given to find the component, the process is called the resolution of forces or velocities, as the case may be. This problem requires the construction of a parallelogram having the given resultant as its diagonal.

Example. Suppose that the resultant of two forces acting at right angles to each other is 100 dynes. The resultant makes an angle of 30° with one of the forces. Find the mag-

nitude of the forces. *Solution*: Draw two lines AX and AY at right angles to each other, Fig. 26. From the point A draw the line AD , making an angle of 30° with AX and having a length of 10 centimeters, each centimeter representing 10 dynes. The line AD represents the resultant (100 dynes) in magnitude and direction. Now from the point D draw a line DB parallel to AY ; also from D draw the line DC parallel to AX . The lines AB and AC represent the magnitude and direction of the components sought.

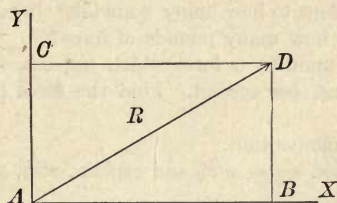


FIG. 26

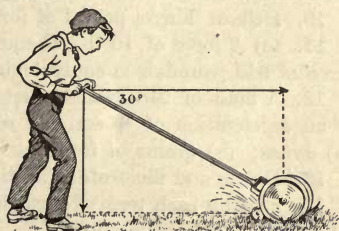


FIG. 27

EXERCISE. 35. A boy pushes a lawn mower with a force of 50 lbs., the force acting in the direction of the handle, which makes an angle of 30° with the horizontal, Fig. 27. Find, by drawing, what part of the force acts (a) horizontally, and (b) vertically.

For further discussion of the subject of Resolution of Forces, see Supplement, 543.

EXERCISES AND PROBLEMS FOR REVIEW

1. Define: Motion, velocity, acceleration. Give illustration of positive acceleration; negative acceleration.
2. Explain the use of the following equations, and explain the meaning of each term: $v = at$; $s = \frac{1}{2} at^2$; $s = \frac{1}{2} gt^2$.
3. A body acted upon by a constant force starts from rest and at the end of the 1st second has a velocity of 5 ft. per second; at the end of the 2d second 10 ft. per second, and so on. What is its velocity (a) at the end of 5 seconds? (b) 5 minutes?
4. (a) Over what space does the body (problem 3) pass in 10 seconds? (b) in 1 minute?

5. How far does it go during the 10th second?
6. A force acting upon a body causes it to change its velocity from 0 to 20 ft. per second during the first 5 seconds. How far will it move under the action of this force in 20 seconds?
7. A body falls from rest for 10 seconds. Over what space, in feet, does it pass (a) during the first 5 seconds of its fall? (b) during the last 5 seconds?
8. Solve problem 7 in metric units, using $g = 980$ cm. per second per second.
9. A body is thrown upward with a velocity of 320 ft. per second.
(a) For how many seconds will it rise? (b) How high will it rise?
10. Define: Force, pound of force, gram of force, poundal, dyne.
11. (a) A force of 10 lbs. is equivalent to how many poundals? (b) A force of 640 poundals is equivalent to how many pounds of force?
12. A mass of 245 grams is acted upon by a force which imparts to it an acceleration of 8 cm. per second per second. Find the force in (a) dynes; (b) grams of force.
13. Define and illustrate: Inertia, momentum.
14. Explain each term of the equation $mv = m'v'$, and explain, also, to what law of motion it applies.
15. Compare the momentum of a body having a mass of 2 ounces and a velocity of 40 ft. per second with that of a body having a mass of 2 lbs. and a velocity of 2 ft. per second.
16. A shot is fired from a cannon having a mass of 1 ton. The velocity of the shot is 1000 ft. per second, that of the cannon 2 ft. per second. Find the mass of the shot.
17. Explain the terms (a) composition of forces; (b) resolution of forces. To what other physical quantities may the principles of composition and resolution apply?
18. A 12 ft. plank spans a stream. A man weighing 200 lbs. crosses on the plank. Call one end of the plank *A* and the other *B*, and assume that the man walks from *A* toward *B*. What part of his weight rests upon each support when he is (a) 4 ft. from *A*? (b) 6 ft. from *A*? (c) 8 ft. from *A*?
19. A boy draws a sled by means of a rope which makes an angle of 40° with the horizontal. He exerts on the rope a force of 30 lbs.
(a) What is the horizontal component of this force acting upon the sled?
(b) The vertical component? Make drawing to illustrate the solution of this problem.
20. A stream, which is a mile wide, flows with a velocity of one mile per hour. A man at *A* on one side desires to cross to *B*, which lies exactly opposite *A*. The man steers his boat directly across stream and rows at

the rate of one mile an hour. (a) Where, with reference to B , will he land? (b) If he directs his boat up stream to a point one mile above B , and rows until he reaches the opposite shore, where will he land? (c) If he heads his boat directly up stream and rows for an hour, where will he be at the end of that time?

For additional Exercises and Problems, see Supplement.

CHAPTER III

MECHANICS OF SOLIDS

CENTRIFUGAL FORCE AND ITS APPLICATIONS

60. Centrifugal Force. *Experiment.* If a small mass be attached to a string and whirled rapidly around, a distinct pull on the string will be felt, becoming greater as the velocity of the rotating body increases. This pull on the string is due to the tendency of the rotating body to obey the first law of motion; that is, it tends to fly off in a straight line. The force which keeps the body from flying off in a straight line and which acts along the string toward the center of rotation is called the *centripetal force*; the reaction of the body against being pulled out of a straight line is the *centrifugal force*. Centripetal force acts toward the center of rotation; centrifugal force is directed away from the center. These forces are equivalent to action and reaction; they are equal to each other in magnitude, and act in opposite directions.

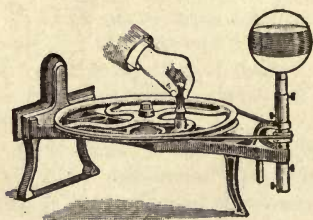


FIG. 28

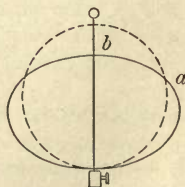


FIG. 29

61. Illustrations of Centrifugal Force. *Experiments with whirling table.*

1. If some mercury and water be placed in a receptacle and rotated rapidly, the mercury will take a position in the equatorial region of the globe, with the water on either side, Fig. 28. The mercury, having a greater mass per unit of volume than that of the water, exerts a greater centrifugal force, and hence gets farthest from the axis of rotation. This experiment illustrates the principle of the modern cream separator, by means of which the cream is separated from the milk.

2. If a circular band of metal be whirled about a central axis, Fig. 29, it will flatten at the poles, due to the fact that the particles in the region *a* have a greater velocity, and hence exert a greater centrifugal force than do the particles in the region of the poles *b*.

62. Other Illustrations of Centrifugal Force. Further illustrations of the action of centrifugal force may be seen in the ordinary affairs of everyday life. For example, the water on a grindstone and the mud on the carriage wheel are thrown off due to the centrifugal force exerted by the rotating bodies. Water in a pail may be whirled around in a vertical plane, Fig. 30. In this case the water is kept in the pail by the centrifugal force tending to throw it away from the center. Also, a bicycle rider in going around a corner instinctively leans inward to overcome centrifugal force, which tends to overturn him. For the same reason the circus rider leans in toward the center of the ring. Likewise, on railway curves the outer rail is laid higher than the inner rail to overcome the centrifugal force exerted by the train. Centrifugal machines for the drying of salt, sugars, and even clothes by rapid rotation are now in common use.



FIG. 30

63. Laws of Centrifugal Force. The laws of centrifugal (also centripetal) force are as follows:

I. *Centrifugal force is proportional to the mass of the rotating body.* That is, the greater the mass the greater the force. For

example, if a mass of 1 pound be whirled around with a given velocity, a given centrifugal force (pull on the string) will be exerted; if, now, a mass of 10 pounds be rotated with the same linear velocity, the centrifugal force will be 10 times as great as in the first case.

II. *Centrifugal force is directly proportional to the square of the velocity.* If the velocity of the rotating body be increased from 1 foot per second to 10 feet per second, the centrifugal force will be increased from 1 to 100.

III. *Centrifugal force is inversely proportional to the radius of rotation.*

These three laws may be expressed by means of an equation,

$$F = \frac{mv^2}{r}$$

in which F is the force, m the mass of the rotating body, v the velocity, and r the radius of rotation. This equation expresses the force in absolute units.

Example. A mass of 4 pounds is whirled around at the end of a string 2 feet in length with a linear velocity of 4 feet per second. Find the pull on the string due to rotation in (a) poundals; (b) pounds. *Solution:* $C.F. = \frac{mv^2}{r} = \frac{4 \times 16}{2} = 32$ poundals = 1 pound of force.

EXERCISE. 1. A mass of 98 grams attached to the end of a string 10 cm. in length is whirled around with a velocity of 10 cm. per second. Find the centrifugal force exerted by the rotating body in (a) dynes; (b) grams of force.

GRAVITATION, GRAVITY, CENTER OF GRAVITY, STABILITY

64. Gravitation. *Gravitation is the force with which every particle of matter in the universe attracts every other particle.* The law of universal gravitation was first announced by Newton as follows: Every body attracts every other body with a force proportional to the product of their masses and inversely pro-

portional to the square of the distance between their centers. This law may be written

$$F = k \frac{mm'}{d^2}$$

in which F is the force of gravitation, measured usually in pounds or dynes; m and m' are the masses of the bodies; d is the distance between their centers; and k is a constant depending on the kind of unit employed. (Supplement, 544.)

By assuming the truth of this general law of gravitation, astronomers have been enabled to describe accurately the motion of the heavenly bodies, as, for example, to predict eclipses, the return of comets, and to discover new planets.

65. Gravity. *Gravity is the attraction which exists between the earth and other bodies.* Gravitation is a general term, referring to the universal attraction which exists between all bodies; gravity is a specific term, referring to the attraction of the earth for bodies usually considered at or near its surface.

66. The Relation of the Weight of a Body to its Position on the Earth. Since the weight of a body is the measure of the force of gravity acting upon it, and since the force of gravity for a given mass varies for different positions with respect to the earth's surface, it follows that the weight of a body may vary from place to place. The relation of weight with reference to the earth's surface may be stated briefly as follows:

1. **Weight at the surface.** The nearer a body is to the center of the earth, *so long as it remains upon the surface*, the greater is its weight. Thus a given mass will weigh more at the base of a mountain than at the top; also, since the polar radius of the earth is 13 miles less than the equatorial radius, and therefore a body at the poles is nearer the center of the earth than at the equator, it follows that a given mass at or near the poles will weigh more than at or near the equator.

2. **Weight above or below the surface.** The weight of a body above or below the surface is less than at the surface.

A mass weighing 100 pounds, for example, at the surface of the earth will weigh less than 100 pounds if taken up in a balloon or down into a mine. (Supplement, 545.)

67. Centrifugal Force and Weight. There are two reasons why a given body weighs less at the equator than at the poles. The first is because the force of gravity, as has already been explained, is less at the equator than at the poles; and the second is, that the centrifugal force is greater at the equator than at the poles. For the last named reason the tendency of all bodies at the equator to fly off into space is greater than at or near the poles. Bodies at the equator have a velocity, due to the rotation of the earth, of more than 1000 miles per hour. The resulting centrifugal force is about $\frac{1}{289}$ of the force of gravity. Now, since centrifugal force is proportional to the square of the velocity, and the square of 17 is 289, it follows that if the earth should rotate 17 times as fast as it now does, bodies at the equator would weigh nothing; and should the rate of rotation increase beyond this point, they would fly off into space.

68. Center of Gravity. *The center of gravity of a body is the point of application of the resultant of all the forces of gravity acting upon it.* It is a point about which the body may be balanced. If a meter stick, for example, be balanced upon the finger, the center of gravity of the stick lies in the body directly above the point of support.

The *center of gravity of a regular homogeneous body* is at its geometrical center. The center of gravity of a cube lies at the point of intersection of its diagonals; that of a circular disc at its center of figure.

The *center of gravity of an irregular body*, as for example a chair, Fig. 31, may be determined by suspending it successively from two different points and noting the intersection of the direction of the plumb line. If a piece of metal, such as iron or lead, be suspended by means of a string, Fig. 32, the device is known as a *plumb line*; that is, a line deter-

mining a vertical direction; the piece of metal is called the "bob." *Experiment.* Suspend from two points E and C an irregular shaped piece of board, Fig. 33, and note

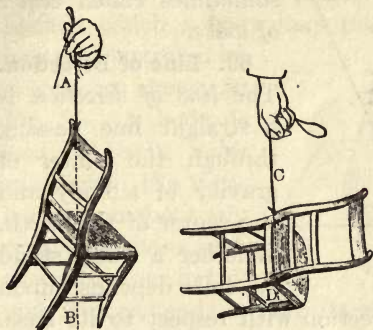


FIG. 31

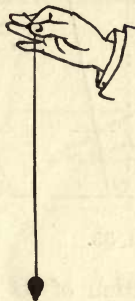


FIG. 32

the point of intersection of the plumb lines E and C . The center of gravity of the board lies on a line passing

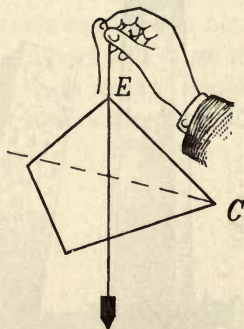


FIG. 33

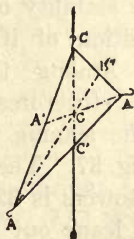


FIG. 34

through the intersection of lines E and C , midway between the faces. In a similar manner it may be shown that the center of gravity of a triangular piece of board lies at the intersection of its median lines, Fig. 34. The center of

gravity of a body may lie entirely outside the material of the body, as in the case of a ring or of a lamp chimney.

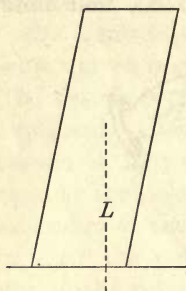


FIG. 35



FIG. 36

Center of gravity is sometimes called *center of mass*.

69. Line of Direction.

The *line of direction* is a straight line passing through the center of gravity of a body and the center of the earth. Whether a body stand or fall depends upon

the position of its line of direction with respect to its base.

If this line fall within the base, Fig. 35, the body will stand; if it fall without the base, Fig. 36, the body will fall. There are in Europe a number of "leaning towers" which illustrate in a very striking manner the relation of the stability of a body to the position of its line of direction. Among the most noteworthy structures of this type are the leaning towers of Bologna, Fig. 37. The taller of these two towers is 320 feet in height and leans out of plumb 4 feet; that is, the middle of the tower leans 4 feet from a plumb line dropped through the middle of the base. The shorter tower is 163 feet in height and is out of plumb by 10 feet. One of the most famous leaning

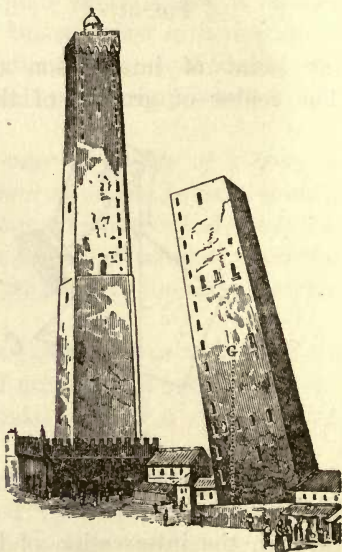


FIG. 37
Leaning Towers of Bologna

towers is that of the bell tower of the Cathedral of Pisa. This tower is 179 feet in height and its top leans from the vertical, as computed in 1910, a distance of 16.5 feet.

70. Three States of Equilibrium. The three states of equilibrium which a body may possess are stable, unstable, and neutral, illustrated by

a cone as shown in Fig. 38. A body is said to be in *stable equilibrium* if a turning motion about any point in its base, such as would occur in tip-

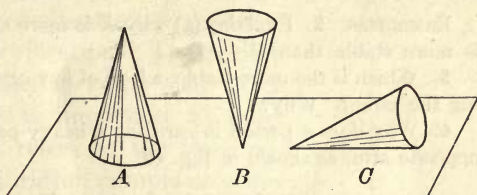


FIG. 38

ping it over, tends to raise its center of gravity. A book lying on the table is in stable equilibrium because its center of gravity rises if it be turned upon its edge. A cone resting upon its base, *A* of Fig. 38, is a good illustration of stable equilibrium.

A body is in *unstable equilibrium* if a turning motion tends to lower its center of gravity. A cone resting upon its vertex is in unstable equilibrium because any turning motion about the point of support will cause its center of gravity to be lowered.

A body is in *neutral equilibrium* if a turning motion neither raises nor lowers its center of gravity, as in the case of the cone

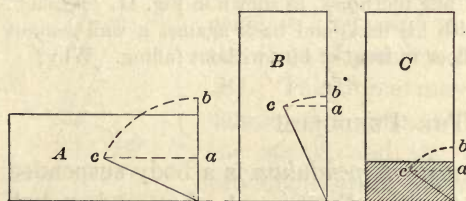


FIG. 39

lying on its side. A spherical ball is also an excellent illustration of neutral equilibrium.

71. Stability of a Body. The stability of a body is deter-

mined by the amount of work required to overturn it; that is, the amount of work necessary to lift the center of mass of the body through a vertical distance ab , Fig. 39. There are two ways by which the stability of a body may be increased; namely,

(a) by broadening the base, (b) by lowering the center of gravity. In *A*, *B*, and *C* of Fig. 39 we have three bodies of the same shape and size. In *C* the center of gravity is lower than in *A* and *B*, due to the loading of one end of the vessel with some heavy material.

EXERCISES. 2. Explain, (a) why *A* is more stable than *B*; (b) why *C* is more stable than *B*.

3. Which is the more stable, a load of hay or a load of coal, each weighing the same? Why?

4. Why does a person in carrying a heavy pail of water throw out the opposite arm, as shown in Fig. 40?



FIG. 40



FIG. 41

5. Two table forks may be balanced on the edge of a tumbler by means of a coin, or better still, a strong toothpick, as shown in Fig. 41. Explain.

6. A person standing with his heels and back against a wall cannot pick up anything from the floor in front of him without falling. Why?

THE PENDULUM

72. Definition of Terms. A *pendulum* is a body suspended so that it may vibrate freely. *Experiment.* Let an iron ball attached to a string be suspended as shown in Fig. 42. This constitutes a pendulum. When it is at rest it lies in a vertical position *PO*. If drawn aside to some point, as *A*, and liberated it will oscillate back and forth, each swing being somewhat shorter than the preceding one, until it finally comes to rest.

A *complete vibration* is a swing from one side to the other and back again; that is, from *A* to *B* and back to *A* again. A *simple vibration* is a swing from one side of the arc to the other; that is, from *A* to *B*. The *amplitude* is one-half the arc described in a single swing.

The *period*, or time of vibration, is the time required to make one vibration. The period of a complete vibration is twice that of a simple vibration. It is important to note that the term period refers to the time required to make one vibration (simple or complete), and has no reference to the time required for the pendulum to come to rest.

73. The Relation of the Period to the Number of Vibrations. If a pendulum make 20 vibrations in 10 seconds, the number of vibrations per second will be $n = \frac{20}{10} = 2$. Also, its period will be $T = \frac{10}{20} = \frac{1}{2}$. Hence it appears that the period of a pendulum is equal to the reciprocal of the number of vibrations per second; that is, $T = \frac{1}{n}$.

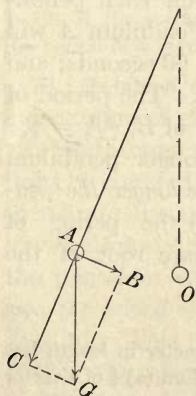


FIG. 43

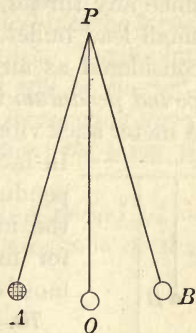
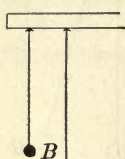


FIG. 42

74. Motion of the Pendulum Explained. Consider the pendulum, Fig. 43, to be drawn aside to the point *A*. It is acted upon by the force of gravity, represented by the line *AG*. This force may be resolved into two components; one, *AC*, producing a tension in the string, and the other, *AB*, tending to produce motion toward *O*. The pendulum, then, tends to move from *A* to *O* due to a component of the force of gravity. It continues to swing beyond *O* due to its inertia.

If there were no friction to interfere, the pendulum would rise as high on one side of the arc as on the other; that is to say, it would never come to rest.

75. Simple and Compound Pendulums. A *simple pendulum* may be defined as a material point suspended by a weightless thread. An actual simple pendulum does not, of course, exist, since any thread, however small, must have some weight. A small lead bullet, however, suspended by a fine thread may be considered as an illustration of a simple pendulum. A *compound pendulum* is any body suspended so as to vibrate freely. A meter stick vibrating about one end is a compound pendulum.



In fact all pendulums in actual use are compound pendulums, differing only in their approximation to the ideal simple type. The pendulum of a clock, for instance, is a compound pendulum in which most of the mass is in the bob.

76. Relation of the Period of a Pendulum to its Length. *Experiment.* This relation may be demonstrated experimentally as follows: Suspend two pendulums *A* and *B*, Fig. 44, having lengths of 1 meter and $\frac{1}{4}$ meter respectively. Determine the period in each case by allowing each pendulum to vibrate for one minute. Pendulum *A* will make 60 vibrations (very nearly) in 60 seconds; and *B*, 120 vibrations in the same time. The period of *A* is, therefore, $\frac{60}{60} = 1$; the period of *B*, $\frac{60}{120} = \frac{1}{2}$.

Thus it appears (a) that the longer pendulum has the greater period; that is, *the longer the pendulum the slower it goes*; and (b) the period of vibration is directly proportional to the square root of the length; that is,

$$T:T' = \sqrt{l}:\sqrt{l'}$$

EXERCISES. 7. If we consider that a pendulum 1 meter in length has a period of 1 second, what will be the period of a pendulum (a) $\frac{1}{4}$ of a meter in length? (b) 4 meters in length?

8. How many vibrations will each of the three pendulums of exercise 7 make in 1 minute?

9. What will be the relative periods of two pendulums whose lengths are 4 ft. and 9 ft. respectively?

77. Relation of Period to Acceleration. *Experiment.* Set in vibration two pendulums, *A* and *B*, of the same length and having iron bobs. Under *A* place the pole of a strong magnet. Pendulum *B* will vibrate due to the force of gravity alone; the vibrations of *A*, on the other hand, will be due to both the force of gravity and the force exerted by the magnet. Pendulum *A* will vibrate faster than *B*; hence its period will be shorter.

According to this experiment, *the greater the force acting upon a pendulum (and hence the greater the acceleration) the faster it goes.*

It has been shown experimentally that the period of a pendulum is inversely proportional to the square root of the acceleration of gravity; that is,

$$T : T' = \sqrt{g'} : \sqrt{g}$$

EXERCISES. 10. How would the period of a pendulum at the poles of the earth compare with its period at the equator? Why?

11. Two pendulums, one at the base of a mountain and the other at the top, are to make the same number of vibrations per minute. Which must be the longer, and why?

12. If the acceleration of gravity were increased fourfold, how would the period of a given pendulum be affected, and how much?

78. Relation of Period to Length of Arc. *Experiment.* If a pendulum of given length, 1 meter for example, be allowed to vibrate through an arc of several degrees, the number of vibrations be counted for one minute, the pendulum then be allowed to vibrate through a very much smaller arc, and the number of vibrations be again counted for a minute, it will be found that the period in each case is practically the same. That is to say, *the period of vibration is independent of the length of the arc*, Fig. 45. This fact was first discovered by Galileo (1566–1642), who observed that the vibrations of a swinging lamp in the Cathedral of Pisa, as timed by his own pulse, occurred in equal intervals, whether the amplitude was large or small. This discovery led to the use of the pendulum as an instrument for the measurement of time in clocks.

It must be noted in this connection, however, that the period of a pendulum is independent of the arc only when the arc is relatively small; indeed, the law holds strictly when the amplitude of vibration is not much greater than three degrees. (Supplement, 546.)

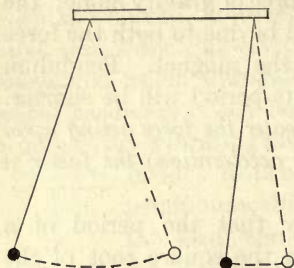


FIG. 45

79. Relation of Period to Mass.

Experiment. Suspend two pendulums having the same length, the bob of one being of iron and that of the other of some light material such as cork or wood, Fig. 46. Let each vibrate for the same time, half a minute say, and count the number

of vibrations. It will be observed that while the pendulum having the greater mass tends to continue in motion for a greater length of time than the lighter one, yet both make the same number of vibrations per unit of time. *The period of vibration is independent of the mass of the bob.* It is important to note that this law does not hold when the vibrations are forced. By a forced vibration of a pendulum we mean one which is due to some other force than gravity, as, for example, the vibration of a pendulum of a clock, which is due to the force of the spring or weight. If the bob be removed from the pendulum of a clock, thus diminishing the mass, the rate of vibration will be much increased.

80. Laws of the Pendulum. The main facts illustrated by the preceding experiments may be expressed in the following laws for the simple pendulum:

I. *The period of vibration of a pendulum is directly proportional to the square root of its length.*

II. *The period of vibration is inversely proportional to the square root of the acceleration of gravity.*



FIG. 46

III. *The period of vibration is independent of the amplitude, provided the amplitude be small.*

IV. *The period of vibration is independent of the mass.*

These laws of the pendulum may be combined into a single equation,

$$T = \pi \sqrt{\frac{l}{g}}$$

in which T is the period, in seconds, of a simple vibration; l is the length of the equivalent simple pendulum in feet or centimeters; g is the acceleration of gravity in feet (32), or in centimeters (980), per second per second. The constant π (3.1416) occurs here, as in a great many mathematical equations, because the equation involves the ratio of the circumference of a circle to its radius.

EXERCISE. 13. Find the period of a simple vibration of a pendulum 108.9 cm. in length at Washington, D. C., g being 980.1.

81. Use of the Pendulum in Measuring Time. The most common use of the pendulum is in the measurement of time. Since its vibrations are performed in equal intervals of time, that is, they are isochronous, all that is needed is some mechanical device to keep the pendulum vibrating and to enable it to regulate the motion of the hands. The motive power of the clock is supplied by weights or springs; the motion of the hands is regulated by means of an escapement, Fig. 47. As the pendulum swings to and fro the projections of the escapement catch alternately in the teeth of the escapement wheel, thus allowing only one tooth to escape for each double swing.

If the escapement wheel, therefore, has 30 teeth, it will rotate once while the pendulum makes 30 complete vibrations.

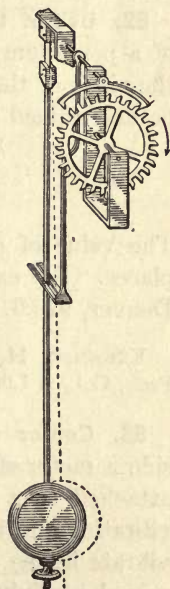


FIG. 47

In order that the periods may be equal, the length of the pendulum must always be the same. In summer the pendulum, however, lengthens, hence the clock tends to lose time; in winter the pendulum shortens and the clock gains time. Corrections must therefore be made for changes in length due to changes in temperature. This may be done by moving the bob up or down by means of a nut or thumb screw. Changes in the length of a pendulum due to changes of temperature may also be automatically corrected by means of compensating devices. A compensation pendulum is one that is made of two or more metals so regulated as to expand in opposite directions (Art. 204), and thereby keep the length of the pendulum constant.

82. Use of the Pendulum in Determining g . If the period of a pendulum of given length be determined by experiment, the value of the acceleration g due to gravity at any place may be determined by means of the equation

$$T = \pi \sqrt{\frac{l}{g}}$$

The value of g has thus been determined for a great many places. For example, at Boston $g = 980.38$; Chicago, 980.26; Denver, 979.6.

EXERCISE. 14. The period of a pendulum 1 meter in length at Pike's Peak, Col., is 1.004 seconds. Find the value of g .

83. Center of Oscillation. Experiment. Suspend side by side a meter stick and a pendulum consisting of a lead bullet attached to a fine thread, Fig. 48. Set the two pendulums vibrating and then shorten the simple pendulum until the two vibrate in the same time. The meter stick represents a compound pendulum; the bullet and thread, a simple pendulum. *The length of the meter stick, considered as a pendulum, is the distance from the point of suspension S to the point O , which corresponds to the position of the bob of the simple pendulum. The*

point O is called the center of oscillation of the compound pendulum. When we speak of the length of a compound pendulum we mean a length that is equivalent to a simple pendulum having the same period. Thus the length of the meter stick, considered as a pendulum, is the distance l measured from the point of suspension S to the point O .

If the compound pendulum be a thin uniform rod, as in the case of the meter stick, its length l , if suspended from the end, is two-thirds of its entire length. If it is not uniform, however, as in the case of a ball bat, the length l has to be determined by experiment.

EXERCISE. 15. What is the period of vibration of a uniform thin rod 12 ft. in length, the value of g being 32 ft. per second per second?

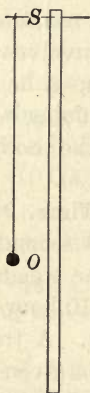


FIG. 48

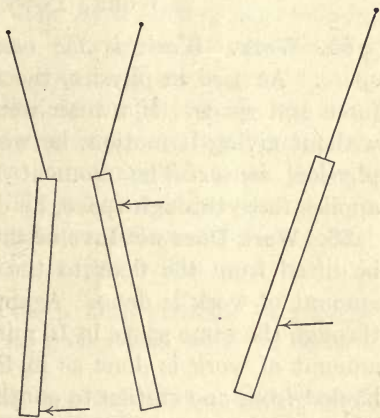


FIG. 49

84. Center of Percussion. Experiment. Suspend a rod by means of a string held in one hand, Fig. 49. (a) Strike the rod near its upper extremity. This end moves in the direction of the blow, and at the same time a sudden jerk is felt by the hand. (b) Again, strike the rod in the same direction near its lower extremity. The upper end moves in a direction opposite

to the stroke and a jerk is again felt by the hand. (c) Now strike the rod in the neighborhood of its center of oscillation. Both ends of the stick move forward together, and no jerk is felt by the hand. This point is called the *center of percussion*. *In a compound pendulum the center of percussion is a point coincident with the center of oscillation.* In the case of the experiment above, we must consider the hand as the point of suspension of the pendulum. The center of percussion is a point where a blow, given or received, is most effective and produces the least strain on the support or axis of motion. The baseball player soon learns at what point on the bat he can deal the most effective blow and at the same time produce the least tingle in his hand.

WORK, POWER, ENERGY

85. Work. *Work is the overcoming of resistance through space.* As used in physics, the term work involves two ideas, force and space. If a man were to hold up a heavy weight without giving it motion, he would not be doing work in the physical sense. The moment he moves the body, that is, applies force through space, he does work.

86. Work Does not Involve the Factor of Time. If a weight be lifted from the floor to the table in 10 seconds, a given amount of work is done. Again, if the same weight be lifted through the same space in 10 minutes, or in 10 hours, the same amount of work is done as in the first case. A train of cars hauled from one station to another requires a given amount of work, no matter what the time involved. Likewise, the work done by the carpenter in sawing a board is measured only by the resistance overcome and the space through which the saw cuts.

$$\begin{aligned} \text{Work} &= \text{force} \times \text{space} \\ w &= Fs \end{aligned}$$

87. Units of Work. Since work is force times space, the units in which work is measured depend upon the units chosen

for force and space. There are, therefore, for work, as in the case of force, two sets of units, the gravitational and absolute.

$$\text{Units of work} \begin{cases} \text{gravitational} & \begin{cases} \text{foot pound} \\ \text{gram centimeter} \end{cases} \\ \text{absolute} & \begin{cases} \text{foot poundal} \\ \text{erg} \end{cases} \end{cases}$$

The foot pound is the work done by a force of one pound acting through a space of one foot. The gram centimeter is the work done by a force of one gram acting through a space of one centimeter. The kilogram meter is sometimes used instead of the smaller unit, the gram centimeter. A kilogram meter is the work done by a force of one kilogram acting through a space of one meter.

The foot poundal is the work done by a force of one poundal acting through a space of one foot. The erg is the work done by a force of one dyne acting through a space of one centimeter.

The two units of work ordinarily employed are the foot pound and the erg. Since the erg is a very small quantity, a larger unit called the joule is sometimes used. A joule is ten million (10,000,000) ergs. The relation of gravitational to absolute units of work is expressed as follows: 1 foot pound = 32 foot poundals; 1 gram centimeter = 980 ergs.

EXERCISES. 16. A weight of 10 lbs. is lifted vertically to a height of 10 ft. Find the work done in (a) gravitational units; (b) absolute units.

17. A force of 10 grams acts through a space of 10 cm. Find the work done in (a) gravitational units; (b) absolute units.

18. A horse pulling a load of 1 ton along a smooth road exerts a force of 500 lbs. How much work in foot pounds is done by the horse if the load be hauled a distance of 1 mile?

88. Power. Power is the time rate of doing work. It is work divided by time; that is,

$$\text{power} = \frac{\text{work}}{\text{time}} = \frac{w}{t}$$

89. Units of Power. The English unit is the horse power (H.P.); the metric unit is the watt, named after James Watt, the inventor of the steam engine.

A horse power is the expenditure of 33,000 foot pounds of work per minute, or 550 foot pounds per second. A watt is equal to 10,000,000 ergs per second; that is, 1 joule per second. A kilowatt (K.W.) = 1000 watts. One H.P. = $\frac{3}{4}$ K.W. (very nearly).

$$H.P. = \frac{\text{foot pounds}}{33,000 \times \text{time in minutes}} = \frac{\text{foot pounds}}{550 \times \text{seconds}}$$

$$\text{watts} = \frac{\text{ergs}}{10,000,000 \times \text{time in seconds}}$$

When the horse power was first proposed as the unit of power it was thought that a strong horse was capable of doing about 33,000 foot pounds per minute. It has since been determined that the power of an ordinary horse for continuous work is considerably below this value. In fact the average horse has a power of $\frac{3}{4}$ H.P.; that of an ordinary man about $\frac{1}{4}$ H.P. The power of the railroad locomotive varies from 500 to 2000 H.P.; that of the engines of our large ocean liners from 10,000 to 40,000 H.P. It is important to note that while the power of an average man is, for continuous work, far below that of a horse, yet for a short time the man may work at a rate greater than that of a horse power. A person in running upstairs, for instance, works at a rate considerably above a horse power.

EXERCISES. 19. During the construction of a building 4950 lbs. of brick were elevated to a height of 20 ft. in 10 minutes. At what rate, in H.P., was the work done?

20. A 500 kilogram weight was lifted to a vertical height of 10 meters in 10 seconds. At what rate was the work done in (a) gram centimeters per second? (b) ergs per second? (c) watts?

21. How many gallons of water can an 8 horse power engine throw to a height of 30 ft. in a quarter of an hour, assuming that a gallon of water weighs 8 lbs.?

22. An engine lifts 198 tons of ore per hour from a mine 1000 ft. deep. Find the power of the engine in (a) H.P.; (b) kilowatts.

90. Energy. *Energy is the capacity that a body has for doing work.* The steam in an engine possesses energy because in expanding it is capable of doing work. The water in a mill dam, the coiled spring of a watch, the muscles of the body, all possess energy because they have the capacity for doing work.

The units in which energy is measured are the same as the units of work; namely, the foot pound, foot poundal, gram centimeter, and the erg.

Energy is of two kinds, potential and kinetic.

91. Potential Energy. *Potential energy is the energy which a body possesses by virtue of its position, or by virtue of its tendency to change chemically.* A body lifted from the floor to the table possesses energy by virtue of its position, because if it were allowed to fall from the table to the floor it would do work. A lump of coal possesses potential energy because of its affinity for oxygen, that is, its tendency to burn. Gunpowder, likewise, possesses potential energy because of its tendency to explode.

The potential energy of a body due to its position may be measured by the work required to put it in place. For example, a body lies upon the table. Its potential energy with respect to the floor is equal to the work required to lift it from the floor to the table.

$$\text{Potential energy} = \text{work} = \text{force} \times \text{space}$$

$$P.E. = w = Fs$$

EXERCISES. 23. A piece of metal weighing 10 lbs. is lifted from the floor to the table, a distance of 3 ft. Find its potential energy in foot pounds.

24. A mass of 20 grams rests on a shelf 3 meters above the floor. What is its potential energy with respect to the floor in (a) gram centimeters? (b) ergs?

25. A mass of 1 kilogram is lifted to a height of 2 meters. Find its potential energy in (a) kilogram meters; (b) gram centimeters; (c) ergs.

92. Kinetic Energy. *Kinetic energy is the energy which a body possesses by virtue of its motion.* We instinctively avoid bodies that are in rapid motion. Experience has taught us that

such bodies possess energy — the greater the motion the greater the energy. Let us consider the case of the bullet and the gun. We have learned from the third law of motion that the momenta of the two are equal. This does not imply, however, that their energies are equal. The energy of the bullet is enormously greater than that of the gun because of its greater velocity. The kinetic energy of a body varies directly as its mass and the square of its velocity. If the velocity of a body be doubled its energy is increased fourfold; if the velocity be trebled its energy is increased ninefold, and so on.

Experiment. If a bullet be dropped from a height of 2 feet into a pail of soft clay it will penetrate to a certain depth, depending on the softness of the clay. If now the bullet be dropped from a height of 8 feet, such that its velocity on striking the clay is twice as great as in the first instance, it will penetrate to nearly 4 times the depth that it did in the former case. It can be shown (Supplement, 547) that the following equation for kinetic energy holds:

$$K.E. = \frac{1}{2}mv^2$$

in which m is the mass of the body and v its velocity. This equation expresses the kinetic energy in absolute units (foot poundals or ergs).

Example. A body having a mass of 16 pounds moves with a velocity of 20 feet per second. Find its K.E. *Solution:* $K.E. = \frac{1}{2}mv^2 = \frac{1}{2} \times 16 \times 400 = 3200$ foot poundals = 100 foot pounds.

EXERCISES. 26. A mass of 64 lbs. is moving with a velocity of 10 ft. per second. Find its K.E. in (a) absolute units (foot poundals); (b) gravitational units (foot pounds).

27. A mass of 196 g., moving with a velocity of 10 cm. per second, has what K.E. in (a) ergs? (b) gram centimeters?

93. Transformation of Energy. Potential energy and kinetic energy are so related that when one disappears the other appears. If a stone be thrown upward it has its maximum

kinetic energy at the instant it leaves the hand, because its velocity at this instant is greatest. As it rises its kinetic energy decreases and its potential energy increases. When it reaches its highest point its potential energy is a maximum; its kinetic energy, zero. Thus, in ascending there is a transformation from kinetic to potential energy; in descending a reverse transformation occurs; that is, the potential energy again becomes kinetic energy, reaching a maximum when the velocity is the greatest.

94. The Conservation of Energy. The law of the conservation of energy states that the energy in the universe is constant in quantity; it cannot be created or destroyed. When work is done, one body loses energy and another gains it. The doing of work, therefore, involves a transference, and often a transformation as well, of energy. The potential energy possessed by a lump of coal is transformed into heat energy in the furnace, then to the steam in the engine, thence to the motion of the wheels, and so on. No energy is destroyed; it is only transformed from one form to another.

MACHINES

95. Definitions. *A machine is a device for transferring or transforming energy.* A steam engine, together with the boiler, is a machine for transforming the potential energy of coal into the kinetic energy of mechanical motion. A dynamo is a machine which may be used for transforming the energy of mechanical motion into the energy of an electric current. A hammer, a pair of scissors, a jack knife, a pencil are all types of machines for transferring energy from one point to another.

96. Friction. Whenever one body slides or rolls over another, friction is encountered. A part of the energy applied to any mechanical device is, therefore, expended in overcoming friction, which manifests itself as a resistance offered to the motion of one body upon another.

The following facts concerning friction have been established by experiment: (a) *Friction depends upon the nature of the substance and the condition of the surfaces, but is independent of the area of the surfaces in contact.* Experiment. Attach a spring balance to a brick, the broad surface of which is in contact with the table, as shown in Fig. 50. By means of the

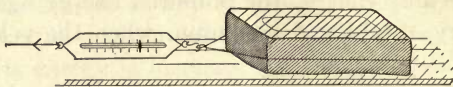


FIG. 50

spring balance, draw the brick over the surface of the table with a uniform motion and note the reading of the balance. Now place the brick with its narrow face in contact with the table, Fig. 51, and draw along as before. The reading of the

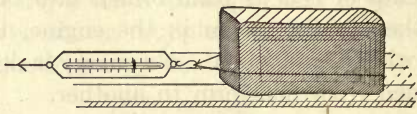


FIG. 51

balance will be the same as in the first case, thus showing that the friction is independent of the area of the surfaces in contact. (b) *Friction is independent of the speed with which one body moves over another, unless the motion be very small.* (c) *Friction is proportional to the force with which the surfaces are pressed together.* Thus if one brick drawn over the table offers a given resistance, two bricks, one placed upon the other, will offer twice as much resistance (friction).

Friction may be reduced by the use of lubricating oils, or in the case of rolling friction by the use of "ball bearings," Fig. 52, as now universally employed in the bicycle.

97. Efficiency of Machines. *The efficiency of a machine is the ratio of the work put into it to the useful work gotten out of it.* This is expressed as follows:

$$\text{Efficiency} = \frac{\text{work out}}{\text{work in}}$$

If a machine deliver 60 foot pounds of useful work for every 100 foot pounds put into it, its efficiency is $\frac{60}{100} = 60$ per cent. This means that 40 per cent of the energy was lost through friction or other sources. A perfect machine, that is, one operating without friction, would have an efficiency of 100 per cent. Since it is impossible to make such a machine, the work done by a machine is always less than the work put into it.

98. Law of Machines. In accordance with the law of the conservation of energy, the work done by a force acting on a machine must equal the work done by the machine. This



FIG. 52

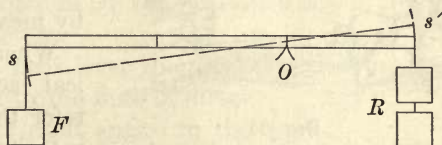


FIG. 53

principle, as applied in mechanics, is expressed by the general law of machines: The force, multiplied by the distance through which it acts, is equal to the resistance overcome, multiplied by the distance through which it acts. This statement of the law, of course, takes no account of friction.

Experiment. The general law of machines may be demonstrated as follows: Weight the end of a rod so that it will balance about some point, for example one-third of the distance from one end, Fig. 53. This constitutes a simple machine. To one end of the lever thus formed suspend a mass of 1 unit F , and to the other end 2 units R . The system is in equilibrium. Now if F be moved through a distance s , R will move through a distance s' . Now, from the law of machines, we may write

$$Fs = Rs', \text{ and also,} \\ Fd = Rd'$$

in which F is the force and d the force arm; R the resistance overcome and d' the resistance arm.

99. Mechanical Advantage. Three advantages may be derived from a machine. (a) We may apply a force in the most

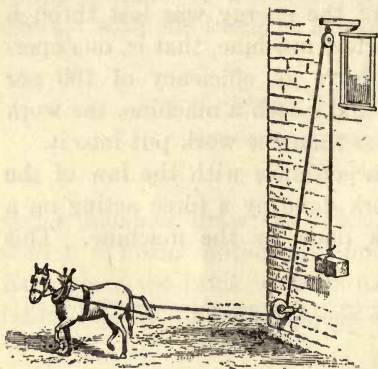


FIG. 54

advantageous direction, as in the lifting of a weight, Fig. 54. (b) We may gain in speed at the expense of force, as in the gearing of a bicycle. (c) We may use a small force to overcome a large resistance, as in the case of lifting a heavy weight by means of a lever.

When we speak of mechanical advantage we usually refer to the third advantage mentioned above. *Mechanical*

advantage is the ratio of the resistance overcome to the force applied; that is,

$$\text{mechanical advantage} = \frac{R}{F} = \frac{d}{d'}$$

100. Simple Machines. There are six so-called mechanical powers or simple machines, as follows: The lever, wheel and axle, inclined plane, pulley, wedge, and screw. All forms of mechanical machines (Supplement, 548), however complex, may be reduced in principle to one or more of these simple types.

In elementary physics it is customary, in solving problems relating to simple machines, to consider the friction factor as negligible and to assume, usually, that the parts of a machine are rigid and without weight. When these factors are taken into account, problems relating to machines are sometimes very complicated and require for solution the principles of advanced mechanics.

101. The Lever. A *lever* is a rigid bar capable of moving about a fixed point called a fulcrum. There are three classes of levers, as shown in Fig. 55, in which F is the force applied

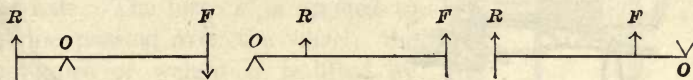


FIG. 55

to one end, R the resistance overcome, O the fulcrum, d the force arm, and d' the resistance arm.

Notes on the lever. The following points should be noted with respect to the lever:

1. The force arm d is measured from the point of application of the force F to the fulcrum O ; the resistance arm d' from the resistance R to the fulcrum.

2. In the case of a bent lever the arms d and d' are measured from the fulcrum to the lines of direction F and R , and at right angles to the same, Fig. 56.

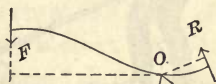


FIG. 56

3. Since for levers of the same length the force arm d is the greatest for the second class, it follows that for a given length, a lever of the second class offers the greatest mechanical advantage, as may be seen in Fig. 55.

4. A lever of the third class gives an advantage in speed at the expense of the force applied.

5. The product of the force into its lever arm is called the moment of the force. *Moment of a force* = Fd . In the study of advanced mechanics the moment of a force is a factor of great importance.

6. The law of the lever is that of the general law of machines; namely,

$$Fd = Rd'$$

EXERCISES. 28. Classify the levers of Figs. 57, 58, 59 with respect to class.

29. If the man of Fig. 60 exert a force of 100 lbs. on the lever, 5 ft. from the fulcrum F , what weight can be lifted, provided the weight arm R is 18 in. in length?

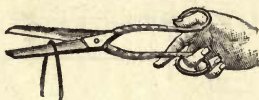


FIG. 57



FIG. 58

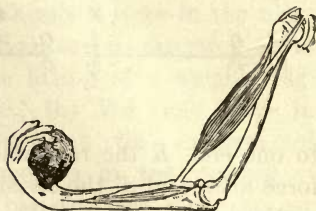


FIG. 59

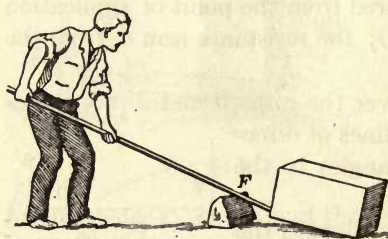


FIG. 60

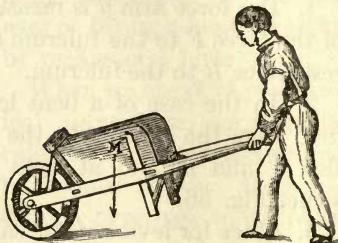


FIG. 61

30. If a weight of 300 lbs. act downward at the point M , Fig. 61, 1 ft. from the axis of the wheel (fulcrum), what upward force must the man exert, providing the distance from M to his hands is 2 ft.?

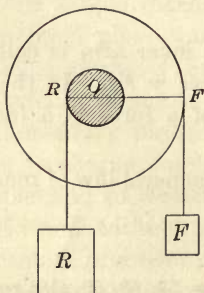


FIG. 62

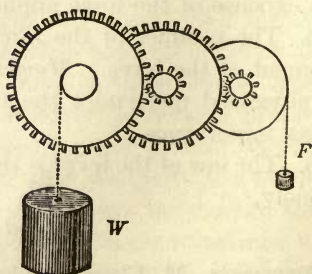


FIG. 63

102. The Wheel and Axle. The *wheel and axle* is an application of the principle of the lever. The large disc, Fig. 62, is the wheel; the small shaded disc is the axle. The force F is applied to a rope passing over the wheel; the resistance or weight R is lifted by means of a rope wound around the axle. The center of the system O is the fulcrum, d the force arm, and d' the resistance arm. The law, as in the case of the lever, is $Fd = Rd'$. Since the radii of the two wheels are proportional to their diameters, and also to their circumferences, we may write $r:r' = d:d' = c:c'$. These values, therefore, may be substituted for d and d' in the equation $Fd = Rd'$.

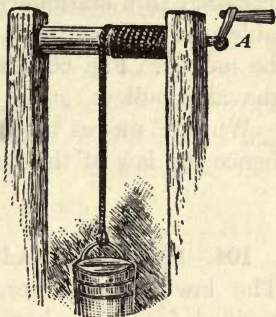


FIG. 64

Other forms of the wheel and axle are seen in the train of cogwheels, Fig. 63, and in the windlass, Fig. 64.

EXERCISES. 31. What force applied at F , Fig. 62, will support a weight of 100 lbs., if the radius of the large wheel be 2 ft. and that of the small wheel (axle) 6 in.?

32. Suppose that for a given wheel and axle, similar to that of Fig. 62, the circumference of the wheel is 5 ft. Find the circumference of an axle such that a force of 20 lbs. will support a weight of 100 lbs.

33. If the length of the lever arm A of the windlass, Fig. 64, is 1.5 ft., and the circumference of the axle is 1.5 ft., what weight will be supported by a force of 10 lbs.? When the handle makes one revolution, through what distance will the weight attached to the rope move?

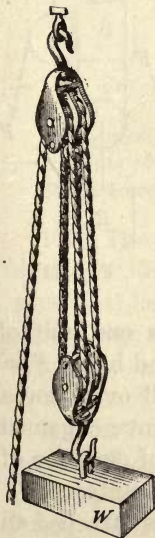


FIG. 65

103. The Pulley. A *pulley* is a wheel turning about an axis in a frame or block. A set of blocks containing one or more pulleys each, together with the attached rope, is called a block and tackle, Fig. 65.

With respect to the point of support, pulleys are of two kinds, fixed and movable. A fixed pulley is one that is fixed or fastened to a stationary support, as a beam or wall. A movable pulley is one that is attached to the weight or object to be moved. Fig. 66 illustrates a system of one fixed and one movable pulley.

When F moves through a distance d , R moves through d' ; hence the law of the pulley is

$$Fd = Rd'$$

104. Mechanical Advantage of the Pulley. *Experiment.* The law of machines, $Fd = Rd'$, may be experimentally verified for a number of typical cases by means of two or three pulleys and a spring balance, arranged as in the following figures:

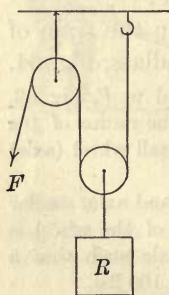


FIG. 66

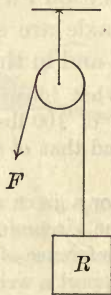


FIG. 67

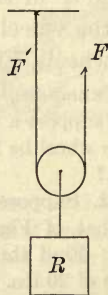


FIG. 68

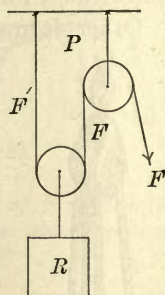


FIG. 69

1. Fig. 67. In this case when F moves down one unit of distance, R moves up one unit, that is $d = d'$, and hence $F = R$. A force of 10 pounds, for example, at F will overcome a resistance at R of 10 pounds. The only advantage gained by the use of the fixed pulley is in the change of direction of the force. A fixed pulley gives no mechanical advantage.

2. Figs. 68, 69. Since we have here two ropes attached to the movable pulley in each case, F will move 2 units of space

for R 1 unit; hence 1 unit of force at F will support 2 units of resistance at R . A force of 10 pounds at F will exert 10 pounds at F' , hence 20 pounds at R . In Fig. 69 the fixed pulley P gives no mechanical advantage; it serves merely to change the direction of F .

3. Fig. 70. Here three ropes are attached to the movable pulley. When F moves 3 units of distance, R will move 1 unit; therefore 10 pounds of force at F will exert 30 pounds at R .

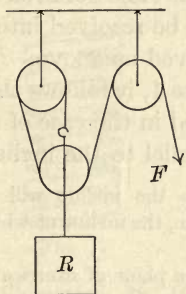


FIG. 70

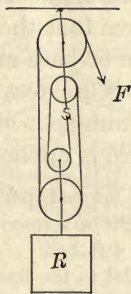


FIG. 71

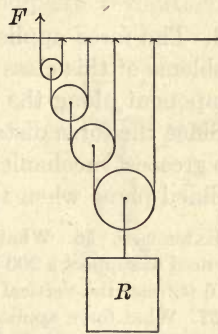


FIG. 72

EXERCISES. 34. A force of 10 units at F , Fig. 71, will balance how many units of resistance at R ?

35. A force of 10 lbs. at F , Fig. 72, will support what weight at R ?

105. The Inclined Plane. The *inclined plane* is a common device for lifting heavy bodies through a vertical height by sliding or rolling them along an incline, Fig. 73. There are three important cases relating to problems of the inclined plane.

1. The force applied parallel to the incline, Fig. 74. The equation $Fd = Rd'$ applies here, where $d = AC$, the length of the incline, and $d' = BC$, the vertical height through which the weight is lifted.



FIG. 73

2. The force applied parallel to the base, Fig. 75. In this case the force distance d is equal to the length of the base AB and $d' = BC$ as before.

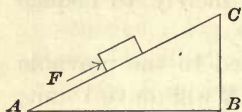


FIG. 74

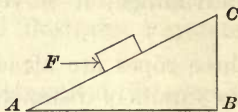


FIG. 75

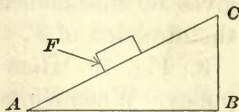


FIG. 76

3. The force applied at an angle, Fig. 76. The solution of problems of this class requires that the force be resolved into a component along the incline or base and solved as above.

Since the force distance d is greatest in case 1, it follows that the greatest mechanical advantage is obtained in the case of an inclined plane when the force is applied parallel to the incline.

EXERCISES. 36. What force applied parallel to the incline will be required to support a 200 lb. weight on a smooth plane, the incline of which is 16 ft., and the vertical height 4 ft.?

37. What force applied parallel to the base of the plane of exercise 36 will be required to support the weight?

106. The Wedge. A *wedge* is a modified form of an inclined plane. It may be considered as being made up of two planes placed base to base. The blade of a pocket knife, the end of a nail, the point of a needle are all wedge-shaped instruments. The wedge is usually used to overcome great resistance through small spaces, as in the splitting of logs, the lifting of heavy weights through very small distances, etc. Since the force is usually applied to the wedge by means of a blow from a hammer or sledge, and the friction factor is very large and cannot be neglected, it is not possible to express a definite relation between the force and the resistance, as stated in the general law of machines.

107. The Screw. A *screw* is a cylinder having a spiral groove cut around its circumference, Fig. 77. The spiral ridge is called the thread and the distance between two consecutive

threads the pitch. The mechanical advantage of the screw is derived from a combination of the principles of the lever and the inclined plane. Fig. 78 shows one form of the screw. The force is applied at the point F on the circumference, and the resistance to be overcome by the downward thrust is at R . The force distance d is the circumference of the circle swept out by the force F in making one complete revolution; the resistance distance d' is the distance between two consecutive threads, that is, the pitch. For one complete revolution of F , R moves downward one thread unit.



FIG. 77

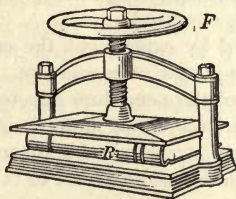


FIG. 78

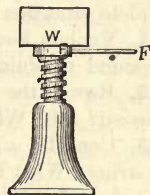


FIG. 79

EXERCISES. 38. If a force of 20 lbs. applied to the circumference of the wheel, Fig. 78, act through a distance of 3 ft. in making one complete revolution, and thus cause the screw to move downward $\frac{1}{4}$ in., what will be the resistance overcome at R ?

39. The lever WF of the jack screw, Fig. 79, is 1 meter in length. If one revolution of the force cause the screw to move upward 1 cm., what resistance will be overcome by a force of 10 kg.?

EXERCISES AND PROBLEMS FOR REVIEW

1. Define and illustrate centripetal force; centrifugal force.
2. Explain the use of the following equation and state the meaning of each term contained therein: $F = \frac{1}{2} \frac{mv^2}{r}$. Does this equation give results in absolute or gravitational units?
3. A mass of 2 lbs. is attached to a string 2 ft. in length and is rotated with a linear velocity of 5 ft. per second. Find the centrifugal force which it exerts in pounds.
4. Distinguish between gravitation and gravity. Explain why a body weighs less at the equator than at the poles.

5. Define center of gravity. Locate the center of gravity (a) in a homogeneous rectangular block; (b) circular disc; (c) triangular piece of board.

6. Explain how to find the center of gravity of an unsymmetrical body, such as a piece of board of irregular shape.

7. Define stable, unstable, and neutral equilibrium, and give illustrations of each.

8. In how many ways may the stability of a body be increased? Make drawing to illustrate and explain why a rectangular body lying on its side is more stable than when standing on end.

9. Define line of direction, and explain the relation of this line to the base of a body with reference to its stability.

10. Define: Simple pendulum, compound pendulum, simple vibration, complete vibration, period, amplitude.

11. Explain how to find by experiment the center of oscillation of a compound pendulum; the center of percussion.

12. How is the period of the pendulum affected (a) when its length is increased? (b) When the force acting upon it is increased?

13. Consider a pendulum consisting of a spherical metal bob attached to a string. What is the relation of its period to (a) its amplitude? (b) the mass of the bob?

14. A given pendulum makes 240 vibrations in 2 minutes. What is its frequency (number of vibrations per second)? (b) What is its period (time of one vibration)?

15. Explain the use of the following equation and the meaning of each term: $T = \pi \sqrt{\frac{l}{g}}$.

16. Find the period of a simple pendulum (a) 4 meters in length; (b) 4 ft. in length.

17. Define: Work, power, energy, potential energy, kinetic energy.

18. Explain the following equations, giving the meaning of each term:

$$W = Fs; P = \frac{w}{t}; P.E. = Fs; K.E. = \frac{1}{2}mv^2.$$

19. Two men, A and B, are at work carrying coal into a cellar. A carries 1 ton into the cellar in 1 hour; B carries 1 ton in an hour and a quarter. (a) Which man does the greater amount of work? (b) Which works at the greater rate?

20. Define: Foot pound, gram centimeter, kilogram meter, foot poundal, erg, horse power, watt, kilowatt.

21. A weight of 1 ton is lifted to a height of 55 ft. in 10 minutes. (a) Find the work done in foot pounds. (b) At what rate is the work done in horse power?

22. A weight of 179,040 kilograms is lifted to a height of 10 meters in 2 minutes. Find the rate at which the work is done in (a) watts; (b) kilowatts; (c) H.P.

23. A stone weighing 2 lbs. is thrown upward to a height of 20 ft. At what point does it have (a) its greatest kinetic energy? (b) its greatest potential energy? Explain the relation between the potential and the kinetic energy which the stone possesses at any instant during its upward or downward motion.

24. What work, in foot pounds, was done on the stone (problem 23) in order to elevate it to a height of 20 ft.? What is its potential energy when at the highest point? How does the P.E. which it possesses at its highest point compare with the K.E. it will have when it strikes the ground?

25. A body having a mass of 10 grams has a velocity of 5 meters per second. Find its kinetic energy in (a) ergs; (b) gram centimeters.

26. A mass of 10 lbs. has a velocity of 5 ft. per second. Find its kinetic energy in (a) absolute units; (b) gravitational units.

27. A bullet having a mass of 1 oz. strikes a target with a velocity of 500 ft. per second. What is the K.E. of the bullet in foot pounds?

28. State the law of machines, and explain each term in the equation $Fd = Rd'$.

29. Make drawings to illustrate the three classes of levers, and write a problem applicable to each.

30. Draw three pulleys as shown in Fig. 70, and find what force will be required to support a weight of 600 lbs.

31. Draw four pulleys as shown in Fig. 71, and find what force will be required to support a weight of 600 lbs.

32. A man desiring to place a barrel upon a platform 4 ft. high uses as an incline a plank 12 ft. in length. He rolls the barrel up the plank. What force applied parallel to the incline will be required to support the barrel upon the plank?

33. A man lifts a weight by means of a jack screw, the distance between the threads of which is $\frac{1}{4}$ in. That is, for every turn of the screw the weight is lifted $\frac{1}{4}$ of an inch. The lever arm of the screw (see Fig. 79) is 3 ft. in length. What weight is the man capable of lifting if he exerts a force of 100 lbs.?

For additional Exercises and Problems, see Supplement.

CHAPTER IV

MECHANICS OF FLUIDS

PROPERTIES OF FLUIDS

108. Definitions. A *fluid* is a substance which will flow. Fluids are divided into liquids and gases. A *liquid* is a fluid which conforms to the shape of the vessel containing it and which has a definite surface. A *gas* is a fluid which tends to fill the containing vessel and which has no definite surface. Mists, fogs, and clouds are fluids which consist of finely divided particles of liquid. The term *vapor* is used by different writers in different senses. It is ordinarily employed to designate a gas which has been formed from a liquid or solid; thus we speak of water vapor in the air, meaning thereby water in a gaseous form.

Hydrostatics treats of the pressure of liquids at rest. *Hydraulics* treats of liquids in motion. *Pneumatics* treats of the pressure and motion of gases. *Pressure is force per unit area.* (Supplement, 549.)

109. Properties of Fluids. 1. *Fluids are perfectly elastic.* If a fluid such as air or water in a containing vessel be subjected to a compressing force, its volume will diminish; if the compressing force be removed the fluid will exactly regain its original shape and volume; hence we say that fluids are perfectly elastic.

2. *Fluids transmit pressure equally in all directions.* If a force be applied to a solid, the body tends to move in the direction of the force. If a force be applied to a fluid, the force is transmitted, not in one direction as in the case of the solid, but

in all directions. Consider a vessel to be filled with highly elastic circular hoops, as shown in Fig. 80. These hoops may be assumed to have the properties of a fluid. A force applied at F is transmitted equally in all directions.

3. *Fluids are compressible.* Gases are highly compressible, differing in this respect in a very marked degree from liquids, which are only slightly compressible. For a pressure of 1 atmosphere water is reduced only by $\frac{1}{20000}$ of its volume, while air is reduced by $\frac{1}{2}$ for the same pressure.

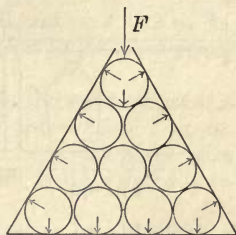


FIG. 80

In all ordinary problems, liquids are considered as being practically incompressible.

110. Pascal's Law. The law relating to the transmission of pressure by fluids was first definitely stated by Pascal, a French scientist. *Pascal's law* may be stated as follows: *Pressure applied to a given area of a fluid enclosed in a vessel is transmitted undiminished to every equal area of the vessel.* Pascal performed a striking experiment to demonstrate the application of this law. A long tube was firmly fixed into the head of a stout cask, Fig. 81. Both cask and tube were then filled with water. The weight of the water in the tube exerted a force on the cask as many times greater than itself as the inner area of the cask was greater than the cross sectional area of the tube. The force exerted by the water in the tube was sufficient to burst the vessel.

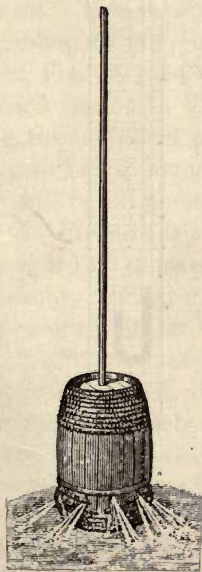


FIG. 81

EXERCISES. 1. A jug, Fig. 82, is filled with water. If, by means of a lever, a force of 10 lbs. be exerted on the cork, cross sectional area 1 sq. in., what will

be the total force transmitted to the vessel if its interior surface be 100 sq. in.?

2. If the cross sectional area of the cork of exercise 1 were $\frac{1}{4}$ sq. in., what would be the total force exerted on the sides of the jug?



FIG. 82

111. Hydraulic Press. An important application of the principle stated by Pascal's law is found in the operation of the *hydraulic*, or *hydrostatic press*. This machine is used where it

is desirable to exert enormous force, such as in the compression of material into very small space for economy in shipment, for the lifting of heavy locomotives that have jumped the track, etc.

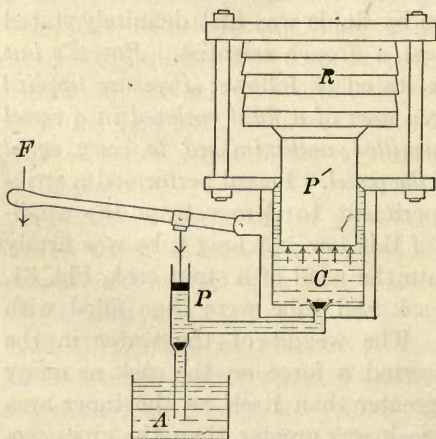


FIG. 83

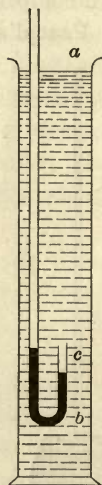


FIG. 84

A sectional outline of a hydraulic press is shown in Fig. 83. The tank *A* contains a liquid which is driven by the force pump *P* into the cylinder *C*, thus acting on the piston *P'*, driving it upward. The force exerted upon the large piston *P'* is as many

times greater than that exerted on the liquid in the force pump P as the cross sectional area of P' is greater than P .

EXERCISES. 3. Suppose that the cross sectional area of P is 2 sq. in. and that of P' is 200 sq. in. A force of 10 lbs. applied to the small piston P will exert what upward force on P' ?

4. A force of 500 lbs. is exerted downward upon the small piston of a hydrostatic press, the cross sectional area of the piston being 2 sq. in. This force is transmitted through the liquid to the large piston, the cross sectional area of which is 200 sq. in. What upward force is exerted upon the large piston?

PRESSURE DUE TO LIQUIDS

112. Pressure in a Liquid. The facts relating to the pressure exerted at any point in a liquid may be stated as follows:

1. *Pressure in a liquid is proportional to the depth. Experiment.* This can be shown by thrusting a bent glass tube containing mercury down into the water enclosed in a tall glass jar, Fig. 84. As the curved portion of the tube moves downward from a to b , the mercury is depressed in the arm c , due to the increased pressure upon it. If the pressure at a given depth be 10 pounds per square inch, then at twice the depth it will be 20 pounds per square inch, and so on.

2. *Pressure is proportional to the density of the liquid.* Mercury is 13.6 times as heavy as water; therefore, for a given depth, mercury will exert 13.6 times as great a pressure as water.

3. *Pressure at a point is equal in all directions.* This fact may be shown by thrusting three bent tubes containing mercury into a vessel of water, Fig. 85. The lower openings of the tubes are all in the same plane, but communicate with the water in different directions. The depression of the mercury in each tube is the same, showing that the pressure in all three directions in the plane ab is the same.

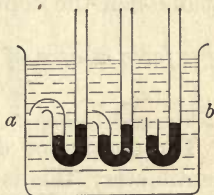


FIG. 85

113. Force Exerted by a Liquid upon the Surface. The total force exerted by a liquid upon a submerged surface depends upon (a) the area of the surface, (b) the depth of the liquid pressing upon the surface, and (c) the density of the liquid. The total force exerted by a liquid upon an immersed surface is written,

$$F = AHD$$

in which F is the force in gravitational units, A the area of the surface pressed upon, H the height of the surface of the liquid above the center of figure (Supplement, 550), and D the density of the liquid. The above equation applies to all submerged surfaces whether vertical, horizontal, or inclined; plane or curved. In elementary physics two cases are, in general, considered.

1. *Force on the bottom of a vessel.* The force exerted by a liquid upon the bottom of a vessel having a horizontal base is

$$\text{force} = \text{area of base} \times \text{height of vessel} \times \text{density of liquid},$$

$$F = AHD$$

2. *Force on the side of a vessel.* The force exerted by a liquid upon a vessel having vertical sides varies directly with the depth of the liquid. At the surface the force is zero; at the bottom it is a maximum. The force has an average value at one-half the depth; hence we may write,

$$\text{force} = \text{area of the side} \times \text{one-half the height} \times \text{density},$$

$$F = \frac{1}{2} AHD$$

The density of distilled water at 4° C. is 1 gram per cubic centimeter; this is equivalent to about 62.5 pounds per cubic foot. In solving problems relating to water pressure it is generally assumed, however, unless stated specifically to the contrary, that the density of water = 1 gram per cubic centimeter = 62.5 pounds per cubic foot.

EXERCISES. 5. Find the force in grams exerted on the bottom of a vessel 10 cm. on each edge, when filled with water.

6. Find the force exerted on the bottom of a vessel 10 ft. on each edge, when filled with water.

7. Find the force exerted on the bottom of a vessel 10 ft. on each edge, when filled with brine, density 1.2 times that of water.

8. Find the force exerted on the bottom of the vessel mentioned in exercise 5, when filled with mercury, density 13.6.

9. Find the force exerted on one side of the vessel mentioned in (a) exercise 5; (b) exercise 6.

114. The Hydrostatic Paradox. We have just learned from the preceding topic that the force exerted by a liquid on the

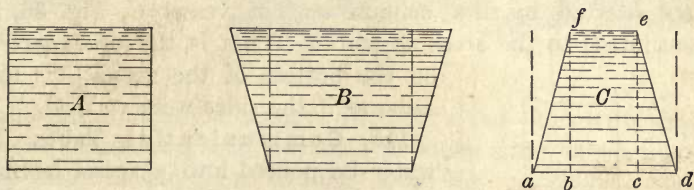


FIG. 86

bottom of a vessel depends only on the area of the bottom, the depth of the liquid, and its density. That is, the pressure is independent of the shape of the vessel. This is called the *hydrostatic paradox*. If three vessels, *A*, *B*, *C*, Fig. 86, having bottoms of the same area, are filled to the same depth with a given liquid, the downward force exerted on the bottom of each vessel will be the same. In *A* the force on the bottom is equal to the weight of the liquid; in *B* the force is less than the weight of the liquid; in *C* the force is greater than the weight of the liquid. This can be demonstrated by means of three vessels, as shown in Fig. 87. The bottoms of the vessels have equal areas. The tube *T* contains mercury, which stands at the

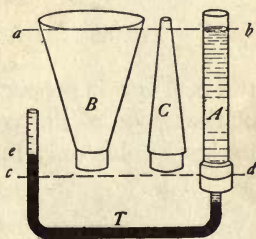


FIG. 87

level cd . When vessel A is screwed upon the standard at d and is filled with water, the mercury falls in one arm and rises in the other from c to e , the height ce measuring the downward force at d . If now the vessels B and C be placed successively upon the standard d and filled with water to the level ab , the mercury in each case will rise to e , thus showing that the force is independent of the shape of the vessel.

The explanation of the hydrostatic paradox lies in the statement of Pascal's law; namely, that the pressure on a given area of the bottom, due to the weight of a column of liquid, is transmitted undiminished to every like area. For example, force exerted by the column $bcef$ of vessel C , Fig. 86, is transmitted to the areas ab and cd . That is, the force exerted on the bottom of the vessel C is the same as if the sides were vertical.

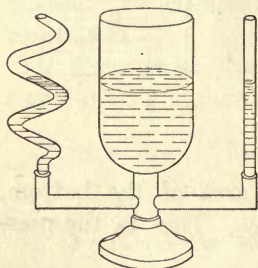


FIG. 88

115. Communicating Tubes. If water be poured into a vessel having two or more *communicating tubes*, Fig. 88, it will rise to the same level in each, no matter what the shape of the vessel. We say that "water seeks its level." A good illustration of this principle is furnished by the water in a tea kettle or tea pot, Fig. 89. This follows because

the pressure is proportional to the depth and is independent of the shape of the vessel. The principle that water will seek its level holds only for liquids at rest. When water is flowing



FIG. 89

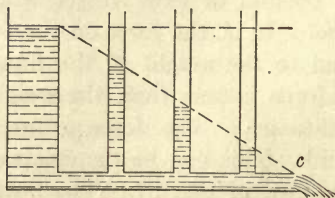
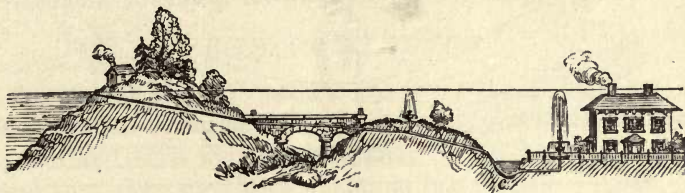


FIG. 90

from an opening, the pressure, and hence the level, decreases as the opening is approached, as shown in Fig. 90. In case the opening at *c* be closed, the water in all the tubes will rise to a common level.

116. City Water Supply. An application of the principle illustrated by liquids in communicating tubes is sometimes



FIG, 91

found in the method of supplying towns and cities with water. Fig. 91 illustrates such a system, in which water is conducted, by means of pipes or "mains," from the source of supply through an aqueduct and thence underground to the gardens and houses beyond. The water in the fountain rises theoretically to the level of the source, but practically not so high on account of the friction due to the air and the pipes. Where there is no natural elevated source of supply, it is necessary to pump the water from wells into reservoirs or standpipes, Fig. 92, situated usually upon high ground, from which it is distributed to the consumers. In some cities no reservoirs are used, the pumping engine being so adjusted as to supply the water at the required pressure.

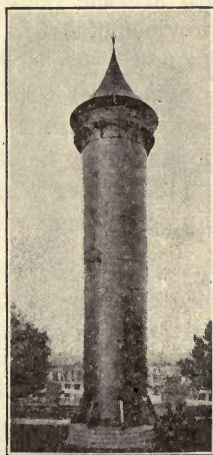


FIG. 92
Standpipe, Lancaster, Pa.

117. Artesian Wells. The tendency of water to seek its level is further illustrated by flowing, or artesian wells. Fig. 93 shows the condi-

tions necessary for such a well. The first stratum is of loose soil; *b* is an impervious layer of clay or rock; *c*, a stratum of gravel; and below this again is another impervious layer, *d*. Water flowing from a height is confined between the two impervious strata *b* and *d* and is under pressure. When this vein of

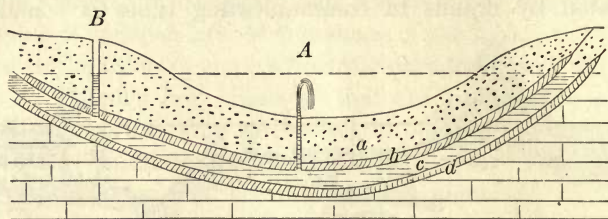


FIG. 93.—Artesian Wells

water is tapped, an artesian well results. An artesian well is usually, but not necessarily, a flowing well; both *A* and *B* are artesian wells. The name “artesian” comes from the province of Artois, in France, where the operation of drilling for flowing wells was first performed.

Sometimes these flowing wells occur in comparatively level regions. In such cases the height of land which furnishes the pressure may lie off at a distance of a number of miles.

118. Water Wheels. One of the oldest methods of obtaining power from water was by means of the water wheel, the old-fashioned and picturesque type, of which is familiar to everyone. Modern water wheels are of two general types, the water motor and the turbine wheel.

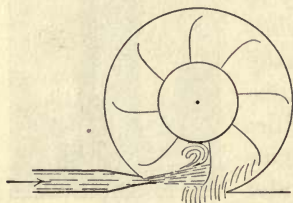


FIG. 94

The *water motor* is often used in cities where water is delivered in pipes under high pressure. Fig. 94 gives a sectional view of a water motor. Water issues with great velocity from the pipe, striking against the blades of the wheel. The rotating system

is enclosed in a metal case, from which the water flows into a waste pipe.

In the case of the *turbine wheel* (Supplement, 551), the water enters the sides through a number of openings in the wheel case, striking against the blades in a manner somewhat similar to that of the water motor.

Hydraulic Elevator, Hydraulic Ram, see Supplement, 552.

BUOYANCY OF LIQUIDS

119. Archimedes' Principle. Experiment. If a stone or piece of metal be weighed in air, by means of a spring balance, Fig. 95, and then weighed in water, it will be found that the body loses weight in the liquid. It is buoyed up by the liquid in which it is immersed. Archimedes (287–212, B. C.), a Greek philosopher, of Syracuse, Sicily, was the first to announce the principle of buoyancy, which has come to be called the *principle of Archimedes*, and which may be stated thus: *A body immersed in a fluid is buoyed up by a force equal to the weight of the fluid displaced.* According to tradition, the manner in which the principle of buoyancy was discovered was somewhat as follows: Hiero, King of Syracuse, possessed a golden crown which he suspected had been adulterated with a base metal by his goldsmith. He applied to Archimedes to detect the fraud. The solution of the problem was suggested to the philosopher while he was in one of the public baths of his native city. He observed the buoyant effect of the water upon his body, and conceived that the buoyant force was equal to the weight of the water displaced. He at once perceived that the purity of the crown could be determined by comparing its specific gravity, as determined by the principle of buoyancy, with that of pure gold. Greatly delighted with his discovery, Archimedes is said to have exclaimed, "Eureka!" (I have found it!)



FIG. 95

120. The Principle Explained. An explanation of Archimedes' principle of buoyancy may be given by means of Fig. 96. Let $abcd$ be one face of a cubical block of unit thickness immersed in water; the downward force acting upon the upper face of the block is equal to the area cd times the depth cf ; that is, the downward force on the block is equal to the weight of the column of liquid $dcfe$. The upward force acting upon the lower face of the block, due to the liquid, is equal to the area of ab times the depth of the liquid bf ; that is, the block is buoyed up by the weight of a column of liquid proportional to $abfe$. The upward force is therefore greater than the downward force, and the difference between the two, $abfe - dcfe$, is

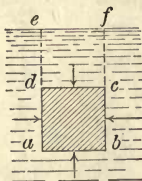


FIG. 96

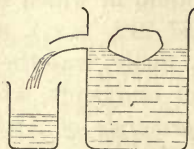


FIG. 97

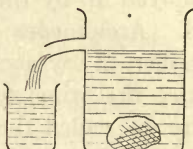


FIG. 98

equal to the weight of a column of liquid $abcd$; hence we say that the block is buoyed up by the weight of the water which it displaces. Whether a body immersed in a fluid will sink or float depends upon the relation between its own weight and the weight of the fluid displaced. If the body be heavier than the fluid displaced, it will sink; if lighter, it will float. If it weighs just as much as the fluid displaced, it will tend neither to sink nor float, but will remain stationary in the fluid wherever placed.

121. Illustrations of Archimedes' Principle. Archimedes' principle applies to bodies that float equally well as to bodies that sink. *A body that floats displaces its own weight; a body that sinks displaces its own volume.* One of the most direct methods of determining the truth of these statements would be to use some such simple device as shown in Figs. 97 and 98.

Consider first the case of a body that is lighter than water, as for example a block of wood. Weigh the block in air and then place it in a beaker full of water, Fig. 97. The floating body displaces a certain amount of water which will flow out into the smaller vessel, and which can then be weighed. It will be found that the weight of the water displaced is just equal to the weight of the floating body. Again, consider the case of a body that is heavier than water. Weigh the body as before in air, and then drop it into the beaker full of water. It will be found that the weight of the water displaced in this case is less than the weight of the body, but that the volume of the water displaced is equal to the volume of the body that sinks. In both cases, that is, for the light body as well as for the heavy, the buoyancy exerted by the liquid is equal to the weight of the liquid displaced.

EXERCISES. 10. A piece of metal having a volume of 10 cc. and a mass of 100 grams will displace (a) what volume of water? (b) how many grams of water? (c) will be buoyed up by what force in water? (d) will have what weight in water?

11. Let a cubic foot of lead weighing 710 lbs. in air be immersed in water. (a) What volume of water will it displace? (b) What weight of water will it displace? (c) What buoyant force will act upon it? (d) What will be its weight in water?

12. A cubic foot of a given substance weighing 60 lbs. is thrown into water. (a) Will it sink or float? (b) How many pounds of water will it displace? (c) What will be the buoyant force acting upon it?

122. Center of Buoyancy. Let Fig. 99 represent a cross section of a boat. G is the center of gravity of the boat and B is the center of buoyancy. The *center of buoyancy* of a floating body is the center of volume of the liquid displaced. The point of intersection of a vertical line through B , with the middle line ab ,

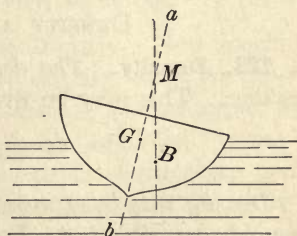


FIG. 99

through G at M is called the *metacenter* of the system; that is, M is the metacenter. So long as the metacenter is above the center of gravity G , the action of the two forces is to right the boat; when the metacenter falls below G , the action of the two forces is to tip the boat over. In Fig. 100 we have

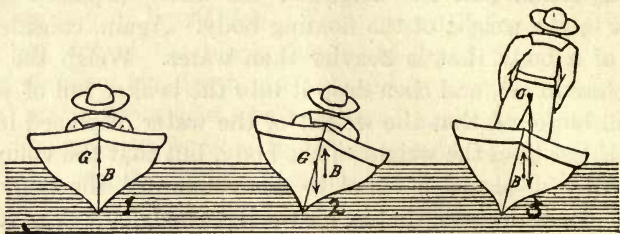


FIG. 100

shown three positions of the center of buoyancy with respect to the center of gravity. In 1, G and B are in the same straight line; in 2, the metacenter lies above G , and the effect of the two forces is to right the boat; in 3, the metacenter lies below G , and the effect of the forces is to overturn the boat.

EXERCISE. 13. Explain why it is dangerous for a person to stand up in a small boat.

DENSITY AND SPECIFIC GRAVITY

123. Density. *The density of a body is its mass per unit volume.* This may be written

$$\text{density} = \frac{\text{mass}}{\text{volume}} = \frac{m}{v}$$

Density may be expressed in grams per cubic centimeter or in pounds per cubic foot. For example, if 10 cubic centimeters of a given sample of brass have a mass of 80 grams, its density, expressed in metric units, will be $\frac{m}{v} = \frac{80}{10} = 8$ grams per cubic centimeter. Likewise, if 2 cubic feet of the same piece

of brass have a mass of 1000 pounds, its density expressed in English units will be $\frac{m}{v} = \frac{1000}{2} = 500$ pounds per cubic foot.

The density of distilled water at 4° C. in metric units is 1 gram per cubic centimeter; in English units, about 62.5 pounds per cubic foot.

124. Specific Gravity. *The specific gravity of a body is the ratio of its density to the density of some substance taken as a standard.* For solids and liquids the standard is distilled water at 4° C.; for gases the standard is air or oxygen. Since for equal volumes at a given place the densities of two bodies are proportional to their weights, we may define specific gravity as the weight of a body divided by the weight of an equal volume of the standard. Now when a body is weighed in air and weighed in water, the loss of weight, according to Archimedes' principle, is exactly equal to the weight of the water displaced, and therefore we may write

$$Sp. g. = \frac{wt. of body in air}{loss of wt. in water}$$

Example. The weight of a given mass of brass in air is 20 pounds; in water, 17.5 pounds. The loss of weight in water = $20 - 17.5 = 2.5$. The specific gravity, therefore, = $\frac{20}{2.5} = 8$. ✓

125. Relation of Specific Gravity to Density. Now specific gravity is always numerically equal to density, *when the latter is expressed in grams per cubic centimeter.* For example, to say that the specific gravity of water is 1 is equivalent to saying that its density is one gram per cubic centimeter; and likewise, to say that the specific gravity of gold is 19.3 is equivalent to saying that gold is 19.3 times as heavy as an equal volume of water, which, in turn, is equivalent to saying that 1 cubic centimeter of gold weighs 19.3 grams.

Since the word density is rapidly displacing the older term specific gravity, and also since nearly all modern density tables

are expressed in grams per cubic centimeter, we shall, in general, in this text, use only the term density, meaning thereby, unless expressly stated to the contrary, grams per cubic centimeter.

EXERCISE. 14. A cubic foot of water weighs 62.5 lbs. What is the weight of a cubic foot of gold?

126. How to Find the Density of a Body. 1. If the body be regular in outline, the most direct method of finding its density is to determine its mass by means of a balance and its volume by direct measurement. For example, if a rectangular block 20 centimeters in length, 10 centimeters in width, and 5 centimeters in height have a mass of 5 kilograms, its density will be

$$\frac{m}{v} = \frac{5000}{20 \times 10 \times 5} = 5 \text{ grams per cubic centimeter.}$$

2. If the body be irregular in outline the simplest method of finding its density is to determine its specific gravity by finding its weight in air and then in water, or in some other fluid chosen as a standard. As we wish to express density in metric units, and since specific gravity is numerically equal to density in these units, it follows that the specific gravity values thus obtained will be equivalent to the density values in grams per cubic centimeter.

EXERCISES. 15. If 10 cc. of lead have a mass of 113 grams, what is its density?

16. If the density of a body be 6 g. per cc. and its volume 10 cc., what is its mass?

17. A piece of glass of density 2.6 g. per cc. has a mass of 13 grams. What is its volume?

18. A given piece of iron weighs 225 lbs. in air, and an equal volume of water weighs 30 lbs. Find (a) the specific gravity of the iron; (b) its density.

127. To Find the Density of a Solid Heavier than Water. If the body be of such a form that its volume cannot readily be determined, as in the case of an irregular piece of metal, the

method of finding its density is to find its specific gravity. Weigh the body in air, then in water. The loss of weight in water is, according to Archimedes' principle, the weight of water displaced; that is, the weight of an equal volume of water. Hence we may write

$$\text{density in g. per cc.} = \text{Sp. gr.} = \frac{\text{wt. in air}}{\text{loss of wt. in water}}$$

Experiment. Either by means of a spring balance, or a beam balance, Fig. 110, determine the specific gravity of an irregular body, such as a stone or a piece of metal.

Example.

Weight of body in air, 10 gm.

Weight of body in water, 8 gm.

Loss of weight in water, 2 gm.

$$\begin{aligned} D &= \frac{\text{wt. in air}}{\text{loss of wt. in water}} \\ &= \frac{10}{2} = 5 \text{ grams per cc.} \end{aligned}$$

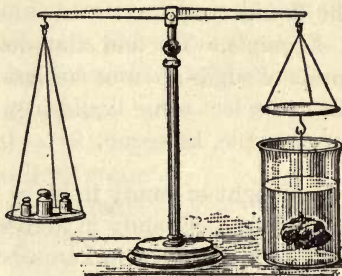


FIG. 101

128. Density of Solids Lighter than Water. Suppose that we wish to find the density of a piece of wood, paraffin, or other body lighter than water. Provide a metal sinker sufficiently heavy to sink the given body. Weigh the sinker in air and in water. Next weigh the given body in air, and then attach the sinker and weigh both in water. The loss of weight of the sinker and body minus the loss of weight of the sinker equals the weight of a volume of water equivalent to the volume of the body.

Example. To find the density of a piece of wood.

Weight of sinker in air = 33 grams

Weight of sinker in water = 30 grams

Loss of weight of sinker = 3 grams

Weight of wood in air = 10 grams

Weight of wood and sinker in air = 43 grams

Weight of wood and sinker in water = 20 grams

Loss of weight of wood and sinker = 23 grams

Weight of water displaced by wood = $23 - 3 = 20$ grams

$D = \frac{20}{40} = 0.5$ gram per cc.

129. Density of Solids Soluble in Water. Weigh the body in air, then in some liquid in which it does not dissolve. Determine its specific gravity relative to this liquid. Multiply the specific gravity thus obtained by the density of the liquid.

Example. To find the density of rock candy. Since all forms of sugar are more or less soluble in water, it will be necessary to select some liquid in which the candy is not soluble, as for example, kerosene.

Weight of candy in air = 20 grams

Weight of candy in kerosene = 10 grams

Loss of weight in kerosene = $20 - 10 = 10$ grams

Sp. g. relative to kerosene = $\frac{20}{10} = 2$

Density of kerosene = 0.8 gram per cc.

Density of candy = $2 \times 0.8 = 1.6$ grams per cc.

130. Density of a Liquid. 1. Specific gravity bottle method. A specific gravity bottle is a small glass bottle having a perforated glass stopper, Fig. 102. First determine the weight of the empty bottle. Next weigh the bottle filled with distilled water. The difference between these two weights is the weight of a given volume of water. Now fill the bottle with the liquid whose specific gravity is to be found, and weigh as before. Again subtracting the weight of the bottle gives the weight of the liquid.



FIG. 102

This weight divided by the weight of the water is the specific gravity.

Example. To find the density of glycerine.

Weight of bottle = 15 grams

Weight of bottle filled with water = 65 grams

Weight of bottle filled with glycerine = 78 grams

$$D = \frac{78 - 15}{65 - 15} = \frac{63}{50} = 1.26 \text{ grams per cc.}$$

2. Density of a liquid by the sinker method. Weigh a sinker in air; then weigh the same sinker in the given liquid; finally weigh the sinker in water. Now since the sinker displaces equal volumes of both the given liquid and of water, it follows that the ratio of the loss of weight in each case is the specific gravity.

Example. Density of alcohol by the sinker method.

Weight of sinker in air = 20 grams

Weight of sinker in alcohol = 18.36 grams

Loss of weight in alcohol = 1.64 grams

Weight of sinker in water = 18 grams

Loss of weight in water = 2 grams

$$D = \frac{1.64}{2} = 0.82 \text{ gram per cc.}$$

3. Density of a liquid by the hydrometer method. A *hydrometer* is a device for determining the density of a liquid by immersing the instrument in the liquid. *Experiment.* If a hydrometer be placed in a jar of water, Fig. 103, the instrument will float in a vertical position, displacing a certain amount of the liquid. Now if the hydrometer be placed in another liquid of greater density, such as a strong solution of salt and water, it will float at a different level. If the instrument be properly calibrated, it will be possible to determine the density of the salt solution directly from the scale. It is evident that a hydrometer with a scale suitable for heavy liquids will not do for light liquids, because the instru-

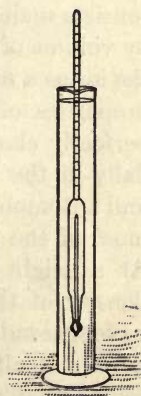


FIG. 103

ment in the latter case would sink to the bottom. Hydrometers, therefore, are calibrated with reference to the use to which they are to be put. A hydrometer calibrated to give the density of milk is called a lactometer; to give the density of syrup, a saccharimeter; the density of acids, an acidimeter, etc.

EXERCISES. 19. A piece of metal weighs 16 grams in air and 14 grams in water. What is its density?

20. A stone having a mass of 20 grams is dropped into a beaker which is "level full" of water, causing 5 cc. of water to flow out. Find the density of the stone.

21. A piece of paraffin, which is lighter than water, weighs 18 grams in air. There is attached to the paraffin a sinker which weighs 40 grams in air and 35 grams in water. The sinker and paraffin together weigh 33 grams in water. Find the density of the paraffin.

22. A sinker weighs 25 grams in air and 20 grams in water. Find the density of a liquid in which it weighs (a) 23 grams; (b) 19 grams.

23. A specific gravity bottle when empty weighs 30 grams. When filled with water it weighs 70 grams; when filled with oil it weighs 60 grams. Find the density of the oil.

PRESSURE DUE TO GASES

131. The Atmosphere. The air composing the atmosphere consists mainly of two gases, oxygen and nitrogen, in the ratio by volume of one part *O* to four parts *N*. These gases exist in the air as a mechanical mixture. The most important physical properties of the air are as follows: (a) Air like all fluids is perfectly elastic; (b) it is highly compressible, as illustrated daily in the compression of air in the pumping up of bicycle and automobile tires. Due to this property of compressibility, most of the atmosphere lies very near the surface of the earth. At a height of 3 miles, altitude of Mt. Blanc, Fig. 104, the density of the air is only one-half that at sea level. Men have ascended in balloons to a height of about 7 miles, at which altitude the density was found to be about one-fourth that at sea level. By means of automatic barometers sent up in balloons, it has been possible to explore the atmos-

phere to a height of some 18 miles. It is estimated that at a height of 35 miles the density of the atmosphere is only about $\frac{1}{30,000}$ of that at the earth's surface. How far beyond this the rarefied atmosphere extends is not definitely known, the distance being variously estimated at from 100 to 500 miles.

132. Air Has Weight. Experiment. Exhaust the air from a hollow globe by means of an air pump. Suspend this globe from the arm of a beam balance and counterpoise, Fig. 105. Now while the balance is in equilibrium, open the stop cock, admitting air into the globe. It will be found that the globe will appear heavier than before, the balance being out of equilibrium, as shown in Fig. 106. The globe when filled with air weighs more than when empty.

The mass of a unit volume of air depends upon the density of the atmosphere, which varies from day to day and from point to point on the earth's surface. Under standard conditions,

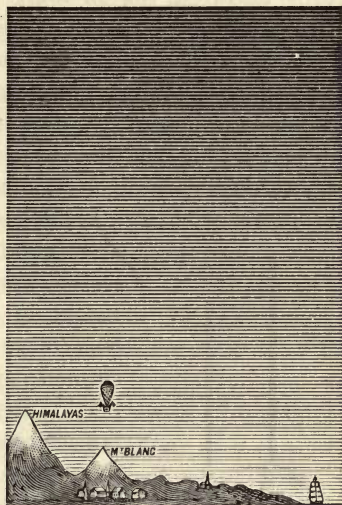


FIG. 104
Density of Atmosphere

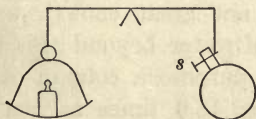


FIG. 105

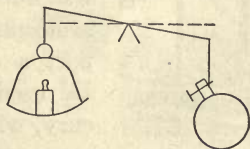


FIG. 106

that is at sea level, and at a temperature of 0° C. (the freezing point of water), the mass of 1 cubic centimeter of air is 0.00129 gram; the mass of 1 cubic foot, 0.08 pound.

133. Rise of Liquids in Tubes. Everyone is familiar nowadays with the method of drinking lemonade and sodas by suction through a tube. Of course it is generally known that by "suction" we mean the exhaustion of the air within the tube, thus allowing the pressure of the atmosphere to force the liquid upward. The fact that a liquid is not drawn up by suction, but is forced up by atmospheric pressure, was not always known, however, as is illustrated by the story of the Duke of Tuscany's pump. In the days of Galileo the phenomenon of suction, so called, was explained by saying that "nature abhorred a vacuum." It is related that the Duke of Tuscany, of Florence, Italy, 1640, had a deep well dug on his estate,

and found, much to his surprise, that the water would not rise in the pump to a height of more than about 30 feet. This was a case, as Galileo put it, in which nature seemed to abhor a vacuum only to the height of 32 feet. Torricelli, a young Italian scientist and pupil of Galileo, undertook to solve the problem of the mysterious behavior of the water in the Duke's deep well pump.

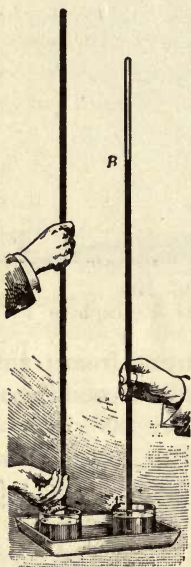


FIG. 107

134. Torricelli's Experiment. Torricelli conceived the idea that the reason the water did not rise to a height greater than 32 feet was due to the fact that the pressure of the atmosphere was not great enough to support a column of water beyond this point. He used for his purpose a column of mercury, which, being 13.6 times as heavy as water, enabled him to use a tube of convenient length. His experiment may be

performed as follows: A glass tube about 80 centimeters in length and closed at one end is filled with mercury, Fig. 107. The open end is closed with the finger and the tube inverted;

the temporarily closed end is then placed under mercury in the dish and the finger removed. The mercury in the tube falls until the pressure due to the column AB is just sufficient to counterbalance the pressure of the air acting upon the surface of the mercury in the dish. At sea level the column AB is about 30 inches, or 76 centimeters in height. The space above the mercury in the tube is called a Torricellian vacuum; it contains a small amount of mercury vapor.

Torricelli concluded from this experiment that air has weight and exerts pressure, and he thus explained the rise of liquids in tubes from which the air has been exhausted. This experiment also demonstrated in a satisfactory manner that the failure of the water to rise to the surface in a deep well pump was not due to the presence of an evil spirit, as was thought, but is due to the fact that the pressure of the atmosphere is sufficient to support a column of water not greater than 32 feet in height.

135. Air Pressure Experiments. *Experiment 1.* Atmospheric pressure may be strikingly illustrated by the tumbler experiment, Fig. 108. In this case a tumbler of water having a sheet of paper pressed firmly over the mouth is inverted. The water and paper are held in position by atmospheric pressure.



FIG. 108

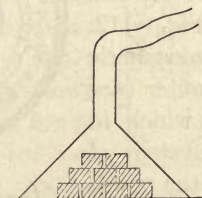


FIG. 109

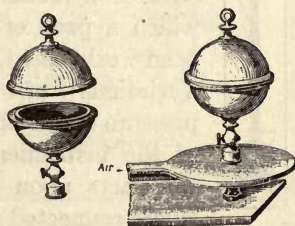


FIG. 110

Experiment 2. The device shown in Fig. 109, consisting of a funnel, a glass plate, and a number of metal weights, illustrates the principle of air pressure in a manner even more striking

than that of the tumbler experiment. The funnel is inverted over the weights, which are piled upon a glass plate, and the air exhausted through the rubber tube by suction (Supplement, 554). Again the atmospheric pressure manifests itself in supporting the plate with the weights upon it.

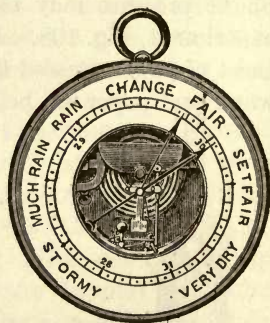
Experiment 3. The experiment with Magdeburg hemispheres (Supplement, 554) is one of the classics of experimental physics. The two hollow hemispheres, Fig. 110, are fitted together and the air exhausted by means of an air pump. The force holding the air together is equal to a pressure of 14.7 pounds per square inch of cross sectional area of the sphere through the center.

136. The Barometer. The *mercury barometer* is a Torricellian tube fastened to a frame having a scale, by means of which the height of the mercury may be read, Fig. 111. If such a barometer be carried up a mountain side the mercurial column will fall, due to the diminished pressure of the atmosphere; if it be taken down into a deep mine or a valley the mercurial column will rise.

The *aneroid barometer* consists of a metallic box from which a part of the air has been exhausted, Fig. 112. Variations of atmospheric pressure affect the outer case of the instrument, which in turn acts upon a system of levers connected to the pointers. One of these pointers



Fig. 111

FIG. 112
Aneroid Barometer

indicates changes of atmospheric pressure, the other indicates probable changes of the weather, as Fair, Change, etc. The advantage of an aneroid barometer lies in the fact that it is small and is therefore easily handled. It is not so reliable,

however, as a mercury barometer, because the mechanical parts of the apparatus are likely to get out of adjustment.

137. Pressure of One Atmosphere. The expression "a pressure of one atmosphere" means the pressure exerted by the atmosphere at sea level and at 0° C. (the freezing point of water). Under standard conditions (sea level and 0° C.) the height of the barometric column is 76 centimeters, which is equivalent to about 30 inches. A column of mercury 76 centimeters in height and having a cross sectional area of 1 square centimeter has a mass of 1033.3 grams. A pressure of one atmosphere, therefore, is equal to 1033.3 grams per square centimeter, which is equivalent to 14.7 pounds per square inch.

One atmosphere = 76 centimeters of mercury = 30 inches of mercury = 1033.3 grams per square centimeter = 14.7 pounds per square inch.

138. Use of the Barometer as a Weather Indicator. Constant use is made of the barometer by the Weather Bureau in forecasting changes in the weather. The relation between barometric readings and the direction of the wind may be studied in connection with the weather map.

A portion of such a map used by the United States Weather Bureau is shown in Fig. 113. The heavy curved lines, called isobars, are lines passing through places of equal atmospheric pressure. At the place marked LOW the atmospheric pressure is least; while at the place marked HIGH the pressure is greatest. The air flows into this "low" region, forming a sort of whirlpool. In the northern hemisphere

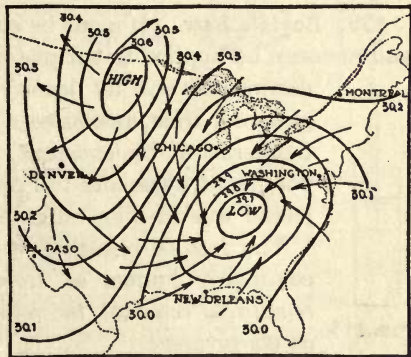


FIG. 113

winds are deflected to the right by the rotation of the earth; hence in the United States the general direction of the wind about these areas of low pressure is counter-clockwise; that is, in the opposite direction to the hands of a clock. If a person stand with his back to the wind, the storm center, that is the region of low barometric pressure, will in general be on his left hand. The observations of the Weather Bureau on barometric pressure for a series of years indicate that these low pressure areas are continually passing over the country with considerable regularity and along pretty well defined paths. The forecaster depends largely upon his knowledge of the movements of these areas in predicting the weather.

The relation of the barometric reading to the probable condition of the weather may be stated as follows: (a) A rising barometer precedes fair weather; (b) a falling barometer precedes foul weather; (c) a sudden fall in the barometer indicates a storm; (d) a steady barometer indicates settled fair weather.

139. Boyle's Law. If a gas be confined in a vessel, Fig. 114, and pressure be applied to the piston, the volume of gas will be diminished and its density increased. An increase of pressure, then, produces a decrease in volume, if the temperature be constant. The relation between the volume of a gas and the pressure to which it is subjected was first investigated by Boyle. (1627-1691.)



FIG. 114

The results obtained were formulated in what is commonly known as *Boyle's law*: *The temperature remaining constant, the volume of a gas varies inversely as the pressure.*

Since the volume decreases in the same ratio as the pressure increases, this law is sometimes written in the form of an equation:

$$pv = c$$

in which C is a constant, as explained in the next topic.

140. Verification of Boyle's Law. Boyle's law and its equation may be verified by means of an apparatus similar to that shown in Fig. 115. To begin with, the mercury stands at the same level in both parts of the apparatus. The air in the chamber *C*, 20 cubic centimeters say, is under a pressure of one atmosphere. Now, applying the law, we have

$$pv = 1 \times 20 = 20.$$

Now suppose that the vessel *V* be elevated as shown in Fig. 115, until the pressure upon the enclosed air is 2 atmospheres. The volume is now 10 centimeters and the pressure is 2 atmospheres. Since we have a different pressure and a different volume to deal with, the law is written

$$p'v' = 2 \times 10 = 20.$$

If the pressure were increased to 4 atmospheres the volume would be decreased to 5 cubic centimeters; hence

$$p''v'' = 4 \times 5 = 20.$$

It will be noted that in every case the product of the pressure times the volume is the same; in other words, *the product of pressure and volume is a constant; that is, $pv = c$.*

141. Boyle's Law Approximate. Investigation has shown that Boyle's law is only approximately true for all gases. For example, those gases which are easily liquefied, such as carbon dioxide (CO_2), sulphur dioxide (SO_2), and chlorine (Cl), show the greatest variation from the law. Within moderate limits of pressure, however, Boyle's law is exceedingly useful in the study of gases.

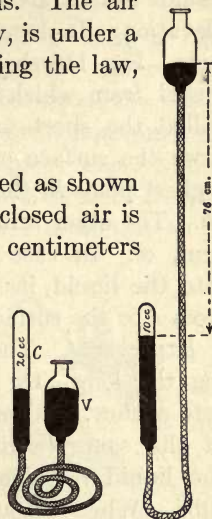


FIG. 115

APPLICATIONS OF AIR PRESSURE

142. The Siphon. The *siphon* is a device for transferring liquids from a given level to a lower level over an intervening elevation. It depends for its operation on atmospheric pressure. Fig. 116 shows a siphon in operation. The arm in the vessel from which the liquid flows is called the short arm; it is measured from the surface of the liquid to the highest point in the bend of the tube, ab . The other arm is called the long arm, ce . In case the long arm dip into the liquid, its length is measured from c to the surface of the liquid.

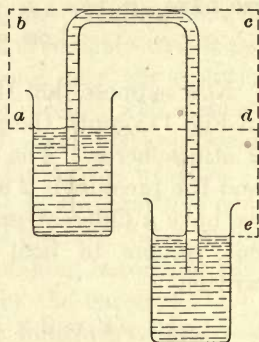


FIG. 116

Experiment. The effect of increasing the long arm is to increase the rate of flow. When the two arms are of the same length the flow ceases; the liquid remains stationary in the tube. When the outer arm is made shorter than the inner arm, the liquid in the tube will flow back into the vessel.

143. Action of the Siphon. Let P be the downward pressure of the atmosphere on the surface of the liquid. Since, according to Pascal's law, pressure is transmitted equally in all directions throughout the liquid, P is therefore the upward pressure on the liquid in the short arm ab . Let p be the pressure due to the weight of the water in this arm. The effective upward pressure, then, on the short arm is $P - p$. Likewise, the upward pressure due to the atmosphere on the long arm cde is also P , the slight difference in pressure due to the difference in level of the two arms being negligible. This means that the upward pressure due to the atmosphere is practically the same on both arms. Now suppose that the pressure due to the weight of the liquid in the long arm cde be p' , then the effective upward pressure on this arm is $P - p'$. Since there is more water in

the long arm than in the short arm, p' is greater than p ; hence it follows that $P - p$ is greater than $P - p'$; that is, the greater upward force acts on the short arm, and hence the liquid flows towards the long arm.

144. The Intermittent Siphon. *Experiment.* Seal a bent glass tube into a funnel, as shown in Fig. 117. Pour water slowly into the vessel. When it rises to the top of the tube a the siphon begins to operate, and continues to flow until the water falls below the opening at b . The siphon ceases to flow until the water is again above a , when it starts again. Because of the character of the flow, such a device is known as an intermittent siphon.

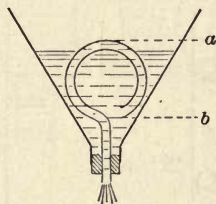


FIG. 117

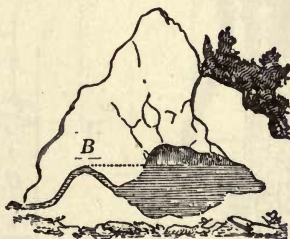


FIG. 118

EXERCISES. 24. Will a siphon work in a vacuum? Why?

25. Explain (a) why the flow ceases when the two arms of a siphon are of the same length; (b) why the liquid flows back into the vessel when the outer arm is shorter than the inner arm.

26. Sulphuric acid has a density of 1.84, that is, it is 1.84 times as heavy as water. (a) Over what height can it be siphoned? (b) Over what height can kerosene (density 0.8) be siphoned? (c) Mercury (density 13.6)?

27. Explain the operation of the intermittent spring, Fig. 118.

145. The Lift Pump. Fig. 119 shows a section of a common cistern pump. The principle upon which it works is illustrated by diagrams A and B of Fig. 120. The pump contains two valves v and v' , both of which open upward. Diagram A illustrates the operation of the valve during a downward stroke of

the piston; *B* shows the condition of the valve during the upward stroke. When the pump is first operated, the action of the piston and valves exhausts the air from the chamber *C*. During this stage it acts as an air pump. *The atmospheric pressure upon the surface of the water in the well forces the water up into the pump until both valves become submerged, Fig. 119.* As the pump continues to operate the valves act exactly as explained in diagrams *A* and *B*, Fig. 120.

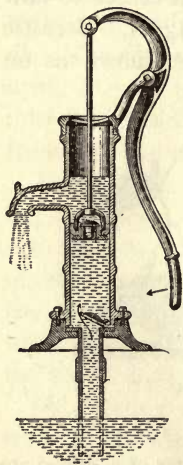


FIG. 119

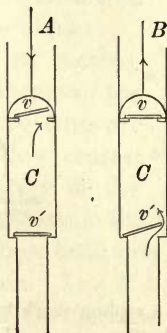


FIG. 120

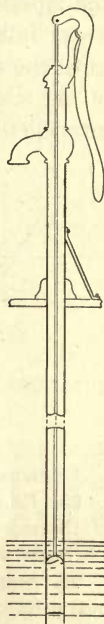


FIG. 121

146. The Deep Well Pump. Since the pressure of the atmosphere is capable of supporting a column of water only about 30 feet in height, a pump having valves near the surface, as in the case of the ordinary cistern pump, would be of no value in lifting water from a well more than about 30 feet deep. To make a deep well pump effective it is necessary to place both valves near the water. In the case of the deep well, such as the drive well for example, the valves are usually placed within a few feet of the water, Fig. 121.

147. The Force Pump. A force pump serves both to lift water from the well and also to deliver it in a steady stream under pressure. In the force pump there is no valve in the plunger, Fig. 122. The chamber *C* is partly filled with air. When water is forced into this chamber by the downward stroke of the plunger *P*, the air is compressed; during the upward stroke of *P*, valve *v* is closed and the air cushion expands, forcing the water through the delivery pipe in a steady stream.

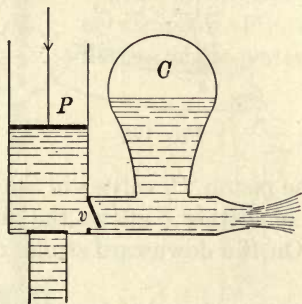


FIG. 122

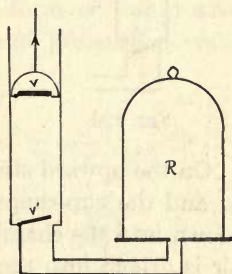


FIG. 123

148. The Air Pump. An air pump does not differ in principle from that of the water pump. The simple exhaust pump is shown in Fig. 123. On the downward stroke of the piston, valve *v* opens, allowing the air in chamber *C* to escape. On the upward stroke of the piston, air is drawn from the receiver *R*.

The pump shown in this figure would not be very effective, however, because the degree of exhaustion obtained would be limited to the pressure required to lift valve *v'*. The modern air pump is, therefore, provided with metallic valves which are ground so as to fit very accurately and which are operated by the mechanical action of the piston. (Supplement, 555.)

149. The Condensing Pump. If the valves of an air pump be reversed and operated as in Fig. 124, air will be forced into the receiver *R*. Such a pump is called a condensing pump.

The common bicycle pump is one of the simplest types of a condensing pump. One valve is connected with the bicycle tire and the other forms part of the piston of the pump, Fig.

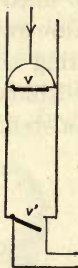


FIG. 124

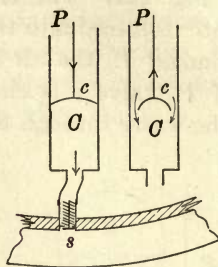


FIG. 125

125. On the upward stroke of the piston P , valve s in the tire closes, and the cup-shaped piece of leather c allows the air to pass down into the chamber C . On the downward stroke of P the air is driven into the tire.

Compressed air is very extensively employed today in operating drills, riveting hammers, and automatic air brakes such as are used on modern electric and steam cars. Compressed air is also used in the diving bell, a device which enables workmen to operate under water. (Supplement, 556.)

150. The Mercury Air Pump. A very good mechanical pump will exhaust a vessel till the pressure of the remaining air in the receiver will support a column of mercury of less than one millimeter in height. In order to get a better vacuum than this it is necessary to use some form of the so-called mercury air pump. These pumps are usually made of glass, mercury playing a part somewhat analogous to that of the piston in the mechanical air pump. The principle upon which the mercury pump operates is shown in Fig. 126. A column of mercury is allowed to fall through a long tube. In passing through chamber C it breaks up into drops each of which serves as a piston to carry a portion of the air downward, thus exhausting the air

from *C*. As the pressure within the receiver is reduced it is obvious that the mercury will rise in the tube *B*, standing at a height of 76 centimeters when the exhaustion is complete.

Pumps of this type are often used in exhausting the air from electric light bulbs.

The most modern type of mercury air pump will produce a vacuum of one millionth of an atmosphere.

151. The Water Jet Pump. The water jet pump, or aspirator, Fig. 127, is a form of pump adapted for use where water under high pressure is available,



FIG. 126

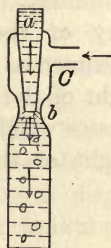


FIG. 127

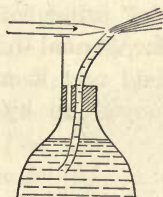


FIG. 128

as from the city water supply. A stream of water under pressure enters the tube *a*, which is constricted at the lower end, thus giving a high velocity at *b*. The air is drawn along with the stream of water in the form of small bubbles, thus exhausting the chamber *C*. With a pump of this kind it is possible, with the water from the city mains, to obtain a vacuum of about 5 centimeters of mercury.

EXERCISE. 28. A pressure of one atmosphere is equivalent to a column of mercury 76 cm. in height. What atmospheric pressure is represented by a pressure equivalent to 5 cm. of mercury?

152. The Ejector. If a strong current of air be blown across the opening of a tube, Fig. 128, the air in the upper part of the tube will be dragged out by the moving column and pressure

within thus reduced. If the lower end of the tube be immersed in a liquid to which the atmosphere has free access, the liquid will be forced to the mouth of the tube, where it is blown into a fine spray. Such an instrument is called an ejector. It explains

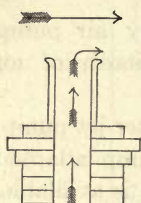


FIG. 129

the principle upon which the atomizer works, also the principle employed in the apparatus used so commonly for the spraying of trees and shrubs.

When a strong wind is blowing across the top of the chimney, Fig. 129, this ejector principle comes into play, and a strong upward draft is created in the chimney.

153. Buoyancy of the Air. According to Archimedes' principle, bodies immersed in a fluid are buoyed up by a force equal to the weight of the fluid displaced. Now air is a fluid and it also possesses weight; hence all bodies in air are buoyed up by the weight of the air displaced. The

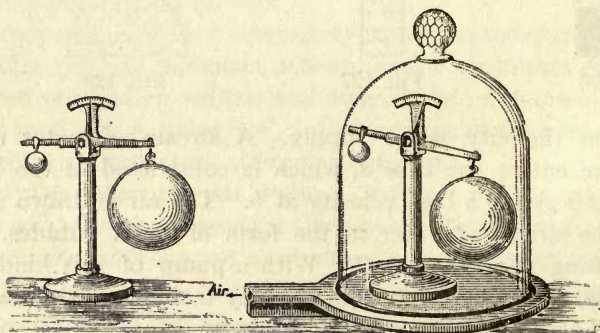


FIG. 130

true weight of a body is its weight in a vacuum; therefore in many accurate scientific measurements of mass it is necessary to reduce the values obtained in air to those corresponding to a vacuum.

There is an old saying that a pound of feathers is heavier

than a pound of lead, when weighed in air. This is in a sense true, because of the buoyancy of the air, as can be shown by the following experiment: Counterbalance in air a hollow spherical vessel against a small metal sphere, Fig. 130. Of course the buoyancy of air upon the large sphere is greater than that upon the small sphere. Now place the balance under the receiver of an air pump and exhaust. As soon as the air is withdrawn from the receiver and its buoyant effects removed, the balance is no longer in equilibrium, the larger sphere now overbalancing the smaller one. Thus the two bodies which apparently had equal masses in air are found to have different masses in a vacuum. The large hollow sphere corresponds to the pound of feathers and the small solid sphere to the pound of lead.

154. The Principle of Buoyancy Applied to the Balloon. A balloon is an air-tight bag, usually made of silk, filled with a gas lighter than air, Fig. 131. The buoyant force tending to elevate it is equal to the weight of air which it displaces. The gas generally used for inflating balloons is either hydrogen or illuminating gas, usually the latter, on account of its comparative cheapness. Under standard conditions a cubic foot of hydrogen has a mass of about 0.006 pound; a cubic foot of illuminating gas, 0.05 pound; a cubic foot of air, 0.08 pound. Now in order to compare the net buoyant effect acting upon equal volumes of two of these gases, we shall consider the following example: Given two toy balloons of the same volume, one containing a cubic foot of hydrogen and the other a cubic foot of illuminating gas, to find the net buoyant effect on each. *Solution:* The weight of air displaced by each balloon is the same; namely, 0.08 pound. The net buoyant effect in each case will therefore be the difference between the weight of air displaced and the weight of the balloon; that is, for

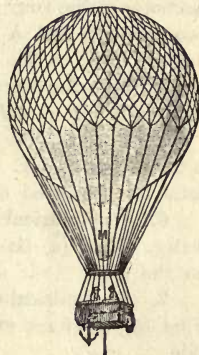


FIG. 131

hydrogen the net buoyant effect will be $0.08 - 0.006 = 0.074$ pound per cubic foot; (b) for illuminating gas, $0.08 - 0.05 = 0.03$ pound per cubic foot. Thus we see that the net buoyant force acting upon the hydrogen balloon is about 2.5 times as great as that acting upon a balloon containing illuminating gas.

Dirigible Balloon and Aeroplane, Supplement, 557.

EXERCISES AND PROBLEMS FOR REVIEW

1. State and illustrate Pascal's law.
2. A tube having a cross section of 2 sq. in. is fitted into the top of a cask, such as shown in Fig. 81, which has a total area of 10 sq. ft. The cask and tube are filled with water. The force exerted by the water in the tube is 10 lbs. Find the total force exerted on the interior surface of the cask.
3. The diameter of a small piston of a hydrostatic press is 1 in.; the diameter of the large piston, 1 ft. (a) What is the ratio of the area of the two pistons? (b) A force of 10 lbs. on the small piston will exert what upward force on the large piston?
4. Give the use of the following equation, and explain meaning of each term: $F = AHD$.
5. A rectangular vessel, height 10 cm., width 20 cm., length 30 cm., is filled with water. Find (a) the force exerted on the bottom; (b) the total force exerted on the four sides.
6. A cylindrical vessel, radius 10 cm., height 20 cm., is filled with water. Find (a) the force exerted on the bottom; (b) the force exerted on the side.
7. A cylindrical tank of radius 5 ft., height 20 ft., is filled with water. Find (a) the force exerted on the bottom; (b) the force exerted on the side.
8. State and illustrate Archimedes' principle.
9. A given substance having a volume of 10 cc. has a mass of 15 grams. (a) How many grams of water will it displace when submerged? (b) Will it sink or float, and why?
10. A cubic foot of a given substance weighing 50 lbs. is thrust under water. (a) What weight of water does it displace? (b) What is the buoyant force acting upon it? (c) What force must be exerted upon it in order to keep it under water?
11. A rectangular piece of aluminum, $2 \times 4 \times 5$ cm., has a density of 2.6 g. per cc. Find its mass.

12. A metallic cylinder having a radius of 2 cm. and a height of 5 cm. has a mass of 628.32 grams. Find its density.

13. A sphere having a radius of 2 cm. has a mass of 150 grams. Find its density.

14. A piece of metal weighs 14 lbs. in air and 12 lbs. in water. (a) What is its specific gravity? (b) its density?

15. A small metal ball weighs 20 grams in air, 18 grams in water, and 17 grams in a given liquid. Find the density of the given liquid.

16. The density of lead is 11.3 g. per cc. What is the weight of a cu. ft. of lead?

17. A specific gravity bottle weighs 25 grams. When filled with water it weighs 65 grams. When filled with a given salt solution it weighs 75 grams. Find the density of the salt solution.

18. When the barometric column stands at a height of 74 cm., what is the pressure of the atmosphere in (a) grams per sq. cm.? (b) dynes per sq. cm.? (c) pounds per sq. in.?

19. A given mass of air under a pressure of 400 grams per sq. cm. has a volume of 100 cc. If the pressure be increased to 600 grams per sq. cm., what will be the volume, the temperature remaining constant?

20. How will the density of the air (problem 19) be affected by the increased pressure, and how much?

21. (a) Under a pressure of one atmosphere, over what height may water be siphoned? (b) When the barometric pressure is 70 cm., over what height may water be siphoned?

22. A sphere having a volume of 100 cc. weighs 1 kilogram in air. What is its weight in a vacuum?

23. A block containing 2 cu. ft. weighs 100 lbs. in air. What is its weight, referred to a vacuum?

24. A balloon has a volume of 60,000 cu. ft. It is filled with illuminating gas. Find (a) the weight of the illuminating gas in the balloon; (b) the buoyant force on the balloon due to the weight of the air displaced.

For additional Exercises and Problems, see Supplement.

CHAPTER V

MOLECULAR MECHANICS

SOME SPECIAL PROPERTIES OF MATTER

155. Properties of Matter Due to Molecular Forces. The properties of a substance are those characteristics which enable us to distinguish it from other substances. *Brittleness*, for example, is a property of glass; *hardness* is a property of the diamond; *tenacity* is a property of iron, etc. There are a great many such properties, among the most important of which are those due to molecular forces. The relation of the properties of a substance to the forces operating between its molecules is very well illustrated in the case of glass. *Experiment.* If a glass rod be bent even a very little it will break. We say it is brittle. If, however, the rod be heated in a flame for a few minutes it will bend very readily. It has lost its property of brittleness and now has the property of flexibility.

In the following topics we shall consider a number of properties of matter which are due mainly to the action of molecular forces.

156. Cohesion and Adhesion. The attraction which exists between molecules of the same kind is called *cohesion*. The attraction between molecules of unlike kind is called *adhesion*. The particles of a piece of chalk are held together by cohesion. On the other hand, when crayon is drawn across the blackboard, a chalk mark is made; the attraction between the chalk and the board is due to adhesion.

Experiment. If a piece of chalk be broken, the parts cannot be united again by pressing them together because the molecules cannot be brought into close enough contact for the

molecular forces to operate. If two pieces of lead, however, are forced together by a twisting motion, the parts will cohere.

157. Examples of Molecular Attraction. A broken plate can be mended by means of cement, a kind of porcelain in a liquid condition, which permits of the molecules being brought into intimate contact. The blacksmith unites two pieces of iron by first heating them red hot and then welding (hammering) them together. The hammering is done for two purposes, (a) to force the molecules into intimate contact, and (b) to give the iron the desired shape.

Experiment. If a clean glass rod be thrust into water and then withdrawn it will be found that a drop of water clings to the glass. In like manner a glass plate clings to water, Fig. 132. This means that the attraction of water for glass (adhesion) is greater than the attraction of water for water (cohesion). In this instance adhesion is greater than cohesion. On pouring water from a glass or pitcher, the tendency of the liquid to adhere to the vessel is well illustrated in Fig. 133.



FIG. 132

158. Tenacity. *Tenacity* is that property by virtue of which a substance resists being pulled apart. A strip of paper is quite easily pulled apart; its tenacity is relatively small. Iron is not easily torn; its tenacity is great.

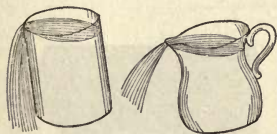


FIG. 133

Experiment. If an iron wire and a copper wire of the same size be suspended from a support and weights added to the free ends until each

wire breaks, it will be found that a much greater weight is required to break the iron than the copper. The relative breaking or *tensile strength* of various metals is about as follows: Lead 1; silver 14; copper 20; iron 30. That is, an iron

rod, for instance, will support 1.5 times as much weight as will a copper rod of the same size.

The tensile strength of steel is about 100,000 pounds per square inch. This means that a steel rod of good quality, having a cross sectional area of one square inch, will support about 100,000 pounds. Some specially drawn steels, however, such as are used in the manufacture of piano wires, may have a tensile strength as great as 300,000 pounds per square inch. A study of the tensile strength of building materials is of great importance in modern engineering practice.

159. Elasticity. *Elasticity* is that property by virtue of which a body tends to recover its shape or volume after being distorted.



FIG. 134

A body is distorted when it is bent, stretched, twisted, or compressed. If a stick be bent, Fig. 134, the molecules on one side may be conceived of as being

crowded together, and on the other side pulled apart. The molecular forces on the one side are repellant, on the other attractive. The action of these forces, tending to straighten the stick, gives rise to the property of elasticity. If a rubber ball be dropped upon the floor it will rebound, due to its elasticity. When the ball strikes the floor it flattens somewhat, the molecules in the ball next to the floor being crowded together. The molecular forces within the ball cause it to recover its shape, and in this recovery occurs the rebound. If a steel ball be dropped upon a marble slab, or other hard substance, upon which there is a coating of fine dust, Fig. 135, it will flatten somewhat before rebounding, as shown by the imprint in the dust, in exactly

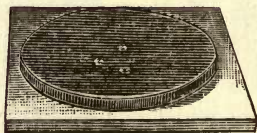


FIG. 135

the same manner as did the rubber ball, only to a much less degree.

160. Elasticity and Distortion. *Experiment.* Let a rod be clamped at one end and a force applied to the other so that the rod is bent (distorted) through a given distance. Now let the bending force be removed, and if the rod move back exactly to its original position, we say that it was bent within its elastic limits. If, however, the rod be bent so far that it does not go back to its former position, we say that it was bent beyond its elastic limit. When a body recovers completely its original form or volume after being distorted, it is perfectly elastic within the limits of its distortion. Liquids and gases are perfectly elastic. That is, no matter how great a force is applied to an enclosed volume of water or air, for instance, or how long applied, these fluids will exactly regain their former volume when the force is removed. Solids, on the other hand, are perfectly elastic within narrow limits; rubber, within wide limits.

161. Hooke's Law. The relation between the force applied to an elastic body and the resulting distortion of the body is expressed by *Hooke's law, which states that within the elastic limits of a body the distortion is proportional to the force applied.*

Experiment. Hooke's law may be illustrated by the apparatus of Fig. 136. A rod is clamped at one end, the other being

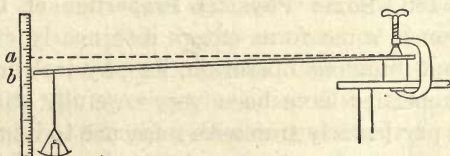


FIG. 136

free to bend. The zero position of the free end is noted, and then a given weight is added. Suppose that this cause a bending of 1 inch. Now if twice as much weight be added, the rod will bend 2 inches, and so on until the elastic limit is reached. According to Hooke's law then, if a given force will bend, twist,

or stretch a body through unit distortion, the application of twice as much force will produce twice the bending, twisting, or stretching; three times the force, three times the distortion, and so on until the limit of elasticity of the body is reached.

EXERCISES. 1. If a force of 10 lbs. stretch a given wire $\frac{1}{100}$ in., what will be the stretch due to a force of 50 lbs.?

2. Assuming that Hooke's law holds, what force will be required to stretch the wire $\frac{1}{10}$ in.?

162. The Relation of the Stretch of a Metal Rod to the Force Applied. *Experiment.* Let two wires of the same length and

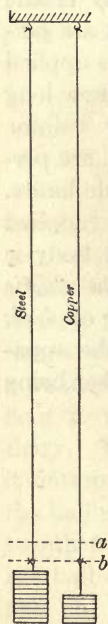


FIG. 137

cross section, one of steel and the other of copper, be suspended side by side, Fig. 137, and weights added until each wire is stretched through a given distance, 0.01 inch say. It will be found that it requires nearly twice as much force to stretch the steel as to stretch the copper. We say, therefore, that the elastic constant, or coefficient of elasticity of steel is about twice that of copper. This elastic constant, or coefficient of elasticity, has been determined for all ordinary metals, and is of great importance to the builder and the engineer, as it enables them to calculate beforehand the length that a given metal will stretch when subjected to a given force.

163. Some Physical Properties of Iron. Since iron in some form enters into nearly every important building operation, its physical and chemical properties have been very carefully studied. This is particularly true with reference to its resistance to forces tending to stretch, bend, or twist it. There are a number of different kinds of iron, the most common being cast iron, wrought iron, and steel.

The physical properties of iron, such as tenacity, brittleness, elasticity, etc., are due mainly to the presence of other substances such as carbon, sulphur, and phosphorus.

Cast iron is a brittle, highly crystalline form, and its physical

properties are due probably to the relatively high percentage of carbon which it contains — 2 to 3 per cent. It expands on solidifying, and to this property is due its use in molding. The hot metal in a liquid condition is poured into molds, and on solidifying it crystallizes and expands, filling exactly the outline of the mold, after which it contracts somewhat. Many familiar articles of household use are made of cast iron, such as kitchen stoves, pots, kettles, etc.

Wrought iron is produced by burning most of the carbon out of cast iron by exposing the molten metal to a stream of air and by working the iron while hot. Wrought iron is softer and very much tougher than cast iron and, unlike the latter, can be welded. The iron used by the blacksmith in most of his work is wrought iron. One of the most familiar examples of wrought iron is the common nail.

Steel contains less carbon than cast iron and more than wrought iron. It is highly elastic, very tenacious, and is capable of being tempered; that is, hardened. Nearly all edge tools are made of steel. The rails of car tracks are in general made of this material, as are also many of the beams and girders of our modern iron buildings.

164. Stiffness and Strength of Beams. In the use of rods and beams in building operations it is often desirable to secure the greatest strength and stiffness with the least weight of material. To accomplish this, beams are not made of compact form, but rather of a cross section, like some of the patterns shown in Fig. 138, since a given amount of material is more effective in resisting a bend or a twist when placed some distance from its center of cross section. For this reason the steel "I" beam is commonly used in the construction of buildings. When it is necessary to combine lightness with great stiffness, the tubular form is almost always used, as in the frame of the flying machine, the bicycle, etc. In nature we find many examples of this combination of

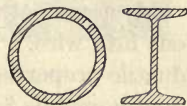


FIG. 138

strength and lightness, as in the case of the hollow stalks of grain, the bones of the body, and the quills of birds.

It must not be understood, however, that a hollow beam is stronger than a solid one of the same dimensions. *A hollow beam is stronger than a solid one of the same weight, but not of the same dimensions.* If the saving of weight and material were no object, beams would always be made solid.

165. Ductility. *Ductility* is that property by virtue of which a substance may be drawn out into threads. Glass at ordinary temperatures is very brittle, but when heated it becomes very ductile. *Experiment.* If a small glass tube be placed in a flame for a few moments it becomes soft and pliable. It can then be drawn out into very fine threads which are flexible and highly elastic, Fig. 139. "Glass wool" which is sometimes

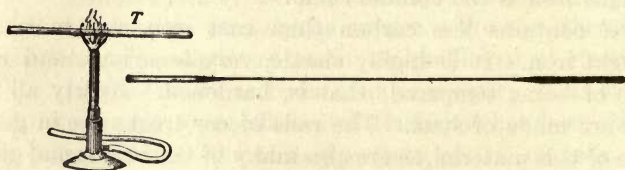


FIG. 139

used for laboratory purposes is made by forcing a stream of air through molten glass, which by this means is blown out into exceedingly fine fibers, somewhat resembling wool in color and elastic properties.

Most metals are ductile, hence are capable of being drawn out into wire. Iron and copper wire are good examples of the ductile properties of these metals. Platinum is one of the most ductile metals known. It can be drawn into wire so fine as to be almost invisible.

When metals are drawn into wire their tenacity is in general increased. If a rod of iron, for example, be drawn into wire and the wire be twisted into a rope or cable, it has been found that the cable thus formed will support a greater weight than

would the original rod. The cable also has the advantage of flexibility. For these reasons iron cables instead of iron rods are used in the construction of certain types of bridges.

166. Malleability. *Malleability* is that property of matter by virtue of which a substance may be beaten out into thin sheets. A good example of a malleable substance is the tin foil which is wrapped around many articles displayed for sale in stores. This foil is made by hammering or rolling the metal tin out into very thin sheets. A distinction here must be made between the metal tin and the so-called "tin" of tinware. The material of which a tin cup, for example, is made is really sheet iron coated with a very thin covering of tin.

Gold is one of the most malleable of metals. Sheets of gold may be beaten out so thin that they are almost transparent. It is estimated that 300,000 such sheets laid one upon the other would be required to make a layer an inch in thickness.

167. Crystallization. When the particles of a substance are arranged in a definite order, the substance is said to be in a *crystalline* condition. When the particles have no definite arrangement, the substance is said to be *amorphous*. Ice is a good example of a crystalline substance. The formation of frost on the window pane in winter gives some idea of the great variety of crystalline forms which water assumes on freezing.



FIG. 140. — Snowflake Crystals

Fig. 140 illustrates a few of the almost infinite variety of the crystalline forms which snowflakes assume.

Blackboard crayon is an example of an amorphous substance. Most forms of glass, such as window glass, tubing, test tubes, beakers, etc., are amorphous.

Carbon occurs in nature in three forms, two of which are crystalline — diamond and graphite; and the third amorphous — coal, charcoal, lampblack.

A great many crystalline substances assume definite geometrical forms, as is illustrated by Iceland spar, a crystal of which is shown in Fig. 141. The nature of a substance is often determined by the crystalline form which it assumes.



FIG. 141

168. Change of Volume Due to Crystallization. Some substances on crystallizing expand. Water, for example, in freezing exerts an enormous expansive force, as is seen in the bursting of water pipes in winter, the upheaval of cement walks, and the disintegration of rocks. Indeed the major portion of the soil is formed by the crumbling of the rocky material of the earth's crust, due, in a large part, to the expansive power of freezing water.

SURFACE TENSION AND CAPILLARY ACTION

169. The Surface of a Liquid. One of the most striking illustrations of the action of molecular forces is found in the study of the surface of a liquid. Consider the molecules of a liquid, as shown in Fig. 142. Molecule *a*, for example, is attracted equally in all directions, within the range of the molecular forces, hence is in equilibrium. A molecule in the surface layer *b*, for instance, is not attracted equally in all directions, the force downward being greater than the force upward, because the molecules of water attract water with a greater force than do molecules of air. Hence it follows that the molecules of the surface layer are drawn downward, and are therefore a little closer to their neighbors than are the molecules of any other part of the liquid. This

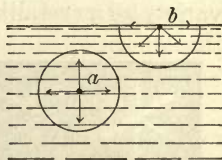


FIG. 142

gives rise to a tension in and parallel to the surface of the liquid, called *surface tension*. The surface of every liquid is under a state of tension and acts exactly as if it were a stretched membrane.

170. Illustrations of Surface Tension. *Experiment 1.* If a wire ring, having a loop of thread tied to it, be dipped into a soap solution and then withdrawn so that a film is formed across it, the loop of thread will lie on the face of the film. If now the film be punctured inside the loop, the thread will spring out into a circle, the tension of the film pulling the loop outward equally in all directions, Fig. 143.

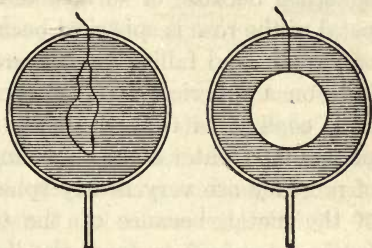


FIG. 143

Experiment 2. If a film be formed across the mouth of a funnel by dipping it into a soap solution, it will be observed that the film creeps down the funnel toward the small end, due to its tendency (surface tension) to contract. The same phenomenon may be seen in the case of the contraction of a soap bubble blown from a pipe, Fig. 144.

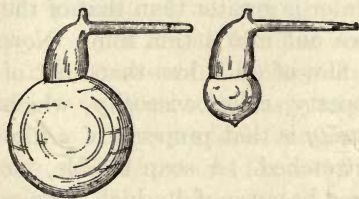


FIG. 144

Experiment 3. Let a film of water be spread out over a clean glass plate. Now put a drop of alcohol on the water and the film will be torn asunder at the point of contact, due to the fact that the surface tension of water is greater than that of alcohol.



FIG. 145

Experiment 4. If by means of a wire holder a needle be carefully placed upon water, the membrane-like surface will cause it to float, Fig. 145.

Certain insects may be seen in the summer time running

about on the surface of still water. They are supported by the tough surface layer of the liquid.

171. The Spherical Form of a Drop of Liquid. When a drop of liquid is free to follow its tendencies, unaffected by forces without, surface tension draws it into the form having the least surface; that is, a sphere. Rain drops tend to become spherical because of surface tension; the drop of dew on the petal of the rose is spherical because of this same force. Drops of molten lead falling from a great height, as in a shot tower, take on a spherical form as they fall, due to surface tension, and, cooling as they descend, retain their shape when they plunge into water at the bottom of the tower. Small globules of mercury are very nearly spherical, despite the great weight of the metal, because of the tendency of the surface layer (surface tension) to force the liquid into the smallest possible volume.

172. Oil on Water. If a drop of light oil be placed on water it quickly spreads out over the surface. This is due to the fact that the surface tension of the water is greater than that of the oil, and hence the latter is drawn out into a thin film. Now while the surface tension of the film of oil is less than that of water, it possesses another property, called viscosity, which gives it toughness. *Surface viscosity* is that property of a film by virtue of which it may be stretched. A soap bubble, for example, may be greatly stretched because of its high surface viscosity. We cannot blow water bubbles as we blow soap bubbles because the surface viscosity of water is small. For this reason the wind blowing over the surface of water easily breaks it up into ripples and waves. A film of oil on the surface of water, on the other hand, is not easily broken because of its high surface viscosity; hence the use of oil in stilling a rough sea around a ship. The action of oil, therefore, in "stilling troubled waters" is not altogether a poetic fancy.

173. Capillary Action. A *capillary tube* is one having a very fine, hair-like bore. If one end of a capillary tube of glass be

thrust into water, the liquid rises, Fig. 146; when thrust into mercury, the liquid falls, Fig. 147. The elevation or depression of the liquid depends on the nature of the curved surface within the tube. When the surface is curved upward, that is, depressed in the middle as in water, the liquid rises; when curved downward, as in mercury, it falls. The surface of all

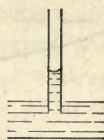


FIG. 146

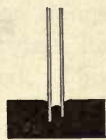


FIG. 147

liquids forms a more or less acute angle with solids; hence there is in general always some capillary action. The surface of water forms a very sharp angle with glass; alcohol very nearly a right angle with silver. The capillary action in the case of water and glass is therefore very pronounced; that between alcohol and silver very slight. If one end of a lump of sugar be dipped into a liquid, coffee for instance, the liquid will rise, due to capillary action, until the lump is saturated. The rise of oil in the wick of a lamp, the flow of the melted wax up the wick of a burning candle, the passage of ink into a blotter, and the flow of ink in the slit of a pen are all familiar illustrations of capillary action.

174. Cause of Capillary Action. The factors which give rise to capillary action are as follows: (a) Nature of the curved surface of the liquid in contact with the tube; (b) surface tension, which furnishes the force to pull the liquid up the tube or to cause it to descend; (c) cohesion between the molecules of the liquid.

Experiment. The action of a force, such as surface tension, along a curved line may be illustrated by a rope hanging between two supports, as shown in Fig. 148. A force acting on a curved line tends to cause it to become a straight line. Hence if the hand exert a pull analogous to the surface tension of the liquid, the rope will take the position shown by the dotted line. Now imagine the curved surface of a liquid to act in a somewhat similar manner. The curved surface tends to become a plane surface, due to the force of surface tension; then the force of

attraction between the liquid and the tube gives a new curved surface, which again tends to become plane, and so on, until the

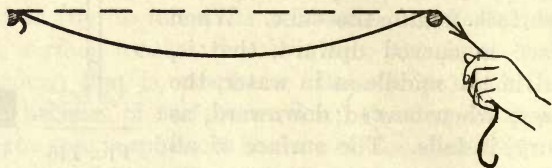


FIG. 148

pull upward or downward is just counterbalanced by the opposing force due to the weight of the liquid.

175. Laws of Capillary Action. The three laws of capillary action may be stated as follows:

I. *When a liquid wets the tube, it will rise; when it does not wet the tube, the liquid will fall.*

II. *The elevation or depression varies inversely as the diameter of the tube.*

III. *The elevation or depression decreases as the temperature increases.*

The first law is illustrated by the rise of water and the depression of mercury in glass tubes. The second law states the relation between capillary action and the diameter of the tube. This relation is illustrated in Fig. 149. From the third law we learn that the temperature affects capillary action. The fact that a rise of temperature decreases capillary action is because an increase of temperature tends to diminish the forces of adhesion, cohesion, and surface tension.

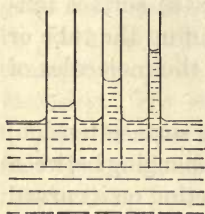


FIG. 149

176. Application. An application of the principle of capillary action is found in the cultivation of the soil during dry weather. When the soil is closely packed, the spaces between its particles are very small; hence capillary action goes on

rapidly and the water within the soil rises to the surface and evaporates. If, however, the soil be kept well cultivated and is loose, the spaces between the particles are large and capillary action goes on slowly. Hence it follows, other things being equal, that soil which is well cultivated will retain its moisture much longer than soil which is not cultivated. This is one of the important principles made use of in the so-called "dry farming" in certain regions of the West.

DIFFUSION AND ABSORPTION

177. Diffusion of Gases and Liquids. One of the best evidences of molecular motion is that furnished by the diffusion of two fluids. *Experiment.* If a tube containing hydrogen (atomic weight 1) be inverted over a similar tube containing oxygen (atomic weight 16) the two gases will mix, notwithstanding the fact that the lower gas (oxygen) is 16 times as heavy as the upper. The diffusion of one gas into another is due to the motion of the molecules of the gases. Hydrogen and oxygen form an explosive mixture. The fact that diffusion actually takes place in the case of hydrogen and oxygen may be demonstrated by applying a lighted match to either tube. A slight explosion occurs, thus showing that the gases have mixed.

Experiment. It can be shown, also, that a heavy liquid will diffuse upward into a lighter one. In a test tube place a solution of litmus. By means of a thistle tube, Fig. 150, pour some sulphuric acid into the tube below the litmus solution. The sulphuric acid is considerably heavier than the litmus solution, and the line of demarcation between the two is sharply defined. In a few hours this line of separation will have moved upward, showing that the heavy acid is diffusing up into the lighter liquid above it.



FIG. 150

Carbon dioxide (CO_2) is about 1.5 times as heavy as air, yet

it mixes readily with the air, due to the tendency of fluids to diffuse.

178. Diffusion of Gases through Solids. Experiment. Lower a glass jar filled with some light gas, such as hydrogen or illuminating gas, over a porous cup, to the lower end of which is sealed a bent glass tube containing colored liquid, Fig. 151.

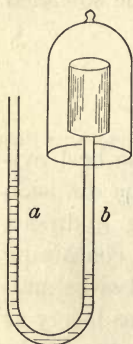


FIG. 151

The light gas in the jar diffuses readily through the walls of the porous cup, thus giving rise to a pressure which is manifested by the rise of the colored liquid in the bent tube. If now the glass jar be removed from over the porous cup, the light gas which has diffused into the cup will now diffuse outward, creating thus a partial vacuum within the cup. This is shown by the fact that the colored liquid in the bent tube rises toward the cup, above its position of equilibrium *ab*.

The lighter a gas the more readily will it diffuse through porous solids. The rate of diffusion of two gases through a porous partition is inversely proportional to the square root of their densities. For example, the weight of hydrogen is to that of oxygen as the ratio of 1:16. Hence the rate of diffusion of hydrogen is to the rate of diffusion of oxygen as $\sqrt{16}:\sqrt{1} = 4:1$. That is, hydrogen will diffuse 4 times as fast as oxygen.

Some gases will diffuse through metals under certain conditions. Carbon monoxide, for example, will diffuse readily through cast iron when the latter is red-hot; hydrogen, also, will diffuse through red-hot platinum.

179. Absorption. Porous solids absorb liquids and gases. The absorption of a liquid by a solid may be illustrated by means of a device shown in Fig. 152. The apparatus consists of a porous cup into the end of which is fitted, by means of a rubber stopper, a bent glass tube containing a little mercury. If the

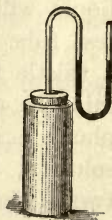


FIG. 152

cup be placed in a beaker of water the mercury will rise in the outer arm of the tube, thus showing an increased pressure inside the cup due to the absorption of water by its walls.

Some solids have the power to absorb gases to a remarkable degree. This is especially true of freshly burned charcoal, as may be demonstrated by means of an apparatus as shown in Fig. 153. Some freshly burned charcoal, cooled to room temperature, is put into a wide-mouthed bottle filled with carbon

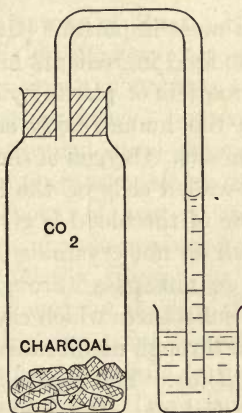


FIG. 153

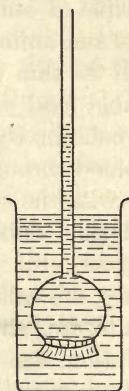


FIG. 154

dioxide, CO_2 . The bottle is then closed with a rubber stopper into which is fitted a bent glass tube as shown. The lower end of the tube dips into a beaker of colored liquid. The charcoal quickly absorbs a considerable portion of the carbon dioxide, thus creating a partial vacuum which is manifested by a rapid rise of the colored liquid in the tube.

180. Osmosis. *Experiment:* If into a thistle tube, over the end of which there has been fastened a membrane, there be put a solution of sugar and water and the tube immersed in a beaker of water, Fig. 154, it will be observed that after a time the liquid in the tube will begin to rise. The water in

the beaker passes through the membrane more readily than the sugar solution passes out. The rise of the liquid in the tube is due to a force called *osmotic pressure*. The process by which liquids pass through membranes is called *osmosis*. A complete and satisfactory explanation of the causes of osmotic action has not yet been found. Suffice it to say that osmosis is due to molecular forces and depends upon the character of the liquids separated by the membrane, and also upon the nature of the membrane itself.

The principle of osmosis plays a most important part in the life of plants and animals. Soluble food ingredients in the soil pass through the thin walls of the rootlets of plants by osmosis. So, too, soluble food substances in the human body enter and leave the circulation by the same means. Oxygen of the air also enters the blood through the thin-walled cells of the lungs by osmosis; likewise the carbon dioxide of the blood is given off.

181. Dialysis. Substances which do not crystallize, such as starch, gelatine, etc., and which do not pass through membranes readily, are called *colloids*; substances which crystallize, as sugars, salts, etc., and which pass through membranes readily when in solution, are called *crystalloids*. The separation of a crystalloid from a colloid is called *dialysis*. If arsenic, for example, is mixed with ordinary articles of food it may be separated from the starchy constituents of the solution by dialysis. The mixture is put into a vessel having a membranous bottom, and the whole is suspended in water. The arsenic readily passes through the membrane into the water, where it may be easily detected by chemical analysis. In this way the presence of crystalloid poisons is sometimes detected in food.

CHAPTER VI

HEAT

TEMPERATURE

182. Nature of Heat. Heat was formerly believed to be a subtle fluid called caloric, which on entering a body produced the phenomena of hotness, burning, etc. About the end of the eighteenth century, however, Count Rumford (Supplement, 559) performed some experiments in connection with the boring of brass cannon which demonstrated that the caloric theory (fluid theory) of heat is untenable, and which indicated that there is some close relationship between heat and motion.

In 1799 Sir Humphrey Davy gave the deathblow to the caloric theory by showing that two pieces of ice can be liquefied at the freezing point by rubbing them together, thus proving that heat is not a fluid, but a form of energy. The experiments of Rumford and Davy laid the foundation for the modern kinetic theory of heat, which assumes that heat is related to molecular motion. According to this theory, if the molecular motion of a body be increased the body becomes hotter; if the motion be decreased it becomes cooler. If a piece of metal be struck with a hammer, both the hammer and the metal become heated, because of the increased molecular motion due to the blow. Also if a piece of iron be thrust into the fire it becomes heated, because of the increased molecular motion imparted by the flame.

Heat, then, may be defined as a form of energy due to the molecular motion of a body.

183. Sources of Heat. The principal sources of heat are: (a) the heavenly bodies, such as the sun, the stars, etc.; (b) the

interior of the earth; (c) chemical action, as in the combustion of wood or coal; (d) electrical energy, as in the heating of the filament of an incandescent lamp; (e) mechanical sources, such as friction, impact, etc.

184. Temperature. The *temperature* of a body is that which determines its degree of hotness or coldness. We speak of boiling water as having a high temperature; of ice cold water as having a low temperature. The temperature of a body is determined by the average kinetic energy of its molecules; the greater the molecular motion the higher the temperature.

185. Sensation as a Measure of Temperature. We depend in a great many cases upon our sensations of hot and cold to determine the relative temperature of bodies. In this manner we may determine that a steam pipe is hot and that ice is cold. This primitive method of determining temperature, however, is not reliable, as may be illustrated by a simple experiment. Take three basins of water, one hot, one cold, and one tepid. Place one hand in the hot water and the other in the cold and hold them there for a moment. Now place both hands in the tepid water. The hand that was in the hot water will feel cool and the hand that was in the cold water will feel warm. Thus the sensations of hot and cold may give us unreliable information as to the actual temperature of the water in the third basin. It is therefore necessary to have some more satisfactory means of measuring temperature, and for this purpose we use a thermometer.

186. Temperature Measured by Expansion. *Experiment.* Temperature is usually measured by means of the expansion of some substance selected as a suitable medium. The expansion of a liquid due to heat may be illustrated by means of a piece of apparatus as shown in Fig. 155. A small flask having a glass tube thrust into the rubber stopper is filled with colored water. If now the bulb be put into a beaker of hot water two things may be observed: (a) First the liquid in the tube falls slightly and then (b) it rises rapidly to a given height. The liquid falls

at first because of the initial expansion of the glass bulb; the heat, however, soon affects the liquid, which, expanding more rapidly than the glass, rises in the tube.

In choosing a thermometric substance it is important to select a liquid which, not only expands readily, but one which also expands at a uniform rate with respect to some standard. Mercury is the substance which is usually chosen for this purpose.

187. The Mercury Thermometer. A *thermometer* is an instrument for measuring temperature. The mercury thermometer consists of a glass tube containing mercury as the expanding substance. The thermometer is constructed and filled as follows:

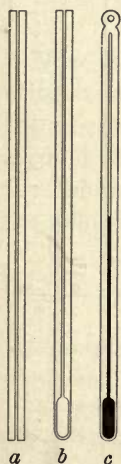


FIG. 156

On the end of a glass tube having a capillary bore *a*, Fig. 156, there is blown a thin-walled bulb *b*. This bulb and a short portion of the capillary are filled with mercury by expelling the air from the bulb by heating, and then thrusting the open end of the tube into mercury, which rises in the tube as the air in the bulb cools and contracts. The instrument is now heated until the mercury expands sufficiently to fill the entire bore, at which time the tube is sealed off at the top, as shown in *c*, thus leaving it air tight. When the thermometer cools the mercury contracts into the lower part, leaving the major portion of the capillary free.



FIG. 155

188. How the Fixed Points of a Thermometer are Determined. In order to establish a thermometer scale it is necessary to determine two fixed points, the freezing point and the boiling point. The *freezing point* is determined by placing the bulb and part of the stem in finely crushed ice, Fig. 157. The mercury in the bulb con-

tracts, and hence the thread of mercury in the capillary falls. The point at which it comes to rest is marked. This is called the freezing point (F.P.); it is the temperature at which water

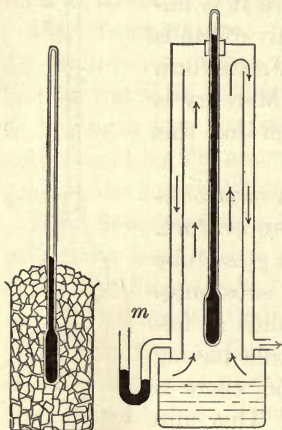


FIG. 157

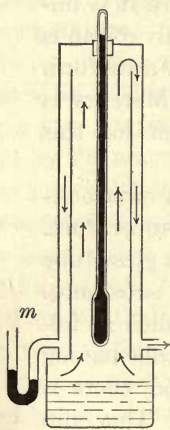


FIG. 158

freezes or ice melts, the two points being practically the same.

The *boiling point* is determined by suspending the thermometer in steam arising from water boiling under a pressure of one atmosphere. The apparatus used in determining the boiling point is shown in Fig. 158. The required pressure of one atmosphere is determined by means of the manometer gauge *m*. As the thermometer becomes heated by the steam, the mercury rises to a certain point,

where it remains stationary. A mark is made on the scale to indicate this point, which is called the boiling point (B.P.).

189. The Fahrenheit Scale. This scale was first used by Fahrenheit, a German scientist. The interval between the freezing point and the boiling point is divided into 180 degrees, usually written 180° . The zero of the scale is set at 32° below the freezing point, thus making the interval from the zero of the scale to the boiling point 212° . There is no advantage, as we now know, in having the zero at 32° below the freezing point. The Fahrenheit scale is inconvenient and remains in use largely through custom.

190. The Centigrade Scale. The Centigrade scale was first suggested by Celsius, a Swedish astronomer and physicist.

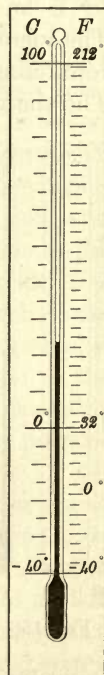


FIG. 159

The interval between the freezing point and the boiling point is divided, as the word centigrade suggests, into one hundred grades or degrees. The zero of this scale is at the freezing point of water. The Centigrade thermometer is used in all scientific measurements of temperature and is, on account of the simplicity and convenience of its scale, coming more and more into common use.

191. Comparison of Centigrade and Fahrenheit Scales. In Fig. 159 the two scales are drawn side by side for comparison. Since the interval between the freezing point and the boiling point is the same for both scales, differing only in the number of units marked on each, we may write

100 units of the C. scale = 180 units on the F. scale,

$$1 \text{ C. unit} = \frac{9}{5} \text{ F. unit},$$

$$1 \text{ F. unit} = \frac{5}{9} \text{ C. unit}$$

Now, bearing in mind that to change from one scale to the other it is necessary to reckon from some fixed point such as the freezing point, and to do this we must always take into account the 32 units between zero and the freezing point of the Fahrenheit scale, the above equations may be expressed in the following convenient forms:

$$\text{To change from C. to F.: } (C. \times \frac{9}{5}) + 32 = F.$$

$$\text{To change from F. to C.: } (F. - 32) \times \frac{5}{9} = C.$$

Examples. (a) A reading of 20° on the C. scale is equivalent to what reading on the F. scale? *Solution:* $(20 \times \frac{9}{5}) + 32 = 68^{\circ} \text{ F.}$

(b) A reading of -20° C. is equivalent to what reading on the F. scale? *Solution:* $(-20 \times \frac{9}{5}) + 32 = -4^{\circ} \text{ F.}$

(c) A reading of $+113^{\circ} \text{ F.}$ is equivalent to what reading on the C. scale? *Solution:* $(113 - 32) \times \frac{5}{9} = 45^{\circ} \text{ C.}$

(d) A reading of $+23^{\circ} \text{ F.}$ is equivalent to what reading on the C. scale? *Solution:* $(23 - 32) \times \frac{5}{9} = -5^{\circ} \text{ C.}$

(e) A reading of -13° F. is equivalent to what reading on the C. scale? *Solution:* $(-13 - 32) \times \frac{5}{9} = -25^{\circ} \text{ C.}$

EXERCISES. 1. Give for the following C. readings their equivalents on the F. scale: (a) $+10^{\circ}\text{C.}$; (b) -10°C. ; (c) $+30^{\circ}\text{C.}$; (d) -30°C. ; (e) -40°C.

2. Give for the following F. readings their equivalents on the C. scale: (a) $+32^{\circ}\text{F.}$; (b) $+77^{\circ}\text{F.}$; (c) $+5^{\circ}\text{F.}$; (d) -4°F. ; (e) -40°F.

192. Limitations of the Mercury Thermometer. The limitations of a thermometric substance are, in general, fixed by its freezing point and its boiling point. Mercury freezes at -39°C. , and consequently cannot be used for measuring temperatures below this point. For measuring temperatures below -39°C. alcohol is often used as the thermometric substance. (Supplement, 560.) This liquid is colored red or blue to render it visible against the glass. The freezing point of alcohol is -130°C. ; its boiling point, $+78^{\circ}\text{C.}$

Mercury boils at 357°C. , under atmospheric pressure, but the boiling may be prevented by an increase of pressure. When it is desired to use a mercury thermometer for the measurement of temperatures higher than its boiling point, it is necessary to fill the space above the mercury in the tube of the thermometer with some inert gas, usually nitrogen. Upon the expansion of the mercury the enclosed nitrogen is compressed and the mercury is prevented from boiling. It is thus not uncommon to find mercury-in-glass thermometers reading up to 500°C.

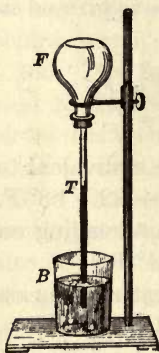


FIG. 160

193. The Air Thermometer. One of the earliest and simplest instruments for measuring temperature is the air thermometer, a device such as is shown in Fig. 160. It consists of a glass bulb and a stem supported vertically, the open end of the tube being immersed in a colored liquid. A small quantity of the air in the thermometer is driven out by heating the bulb, thus allowing the colored liquid to rise a short distance up the tube. If the temperature now rise, the air in the bulb

expands and the colored liquid in the stem falls. When the temperature falls, the liquid in the stem rises. The air thermometer is very sensitive and, in a modified form, is used in making certain accurate scientific measurements.

194. The Clinical Thermometer. This instrument is used by physicians and nurses in taking the temperature of the human body. It is a mercury-in-glass thermometer, Fig. 161, and is characterized by having a narrow constriction c in the capillary. When the thermometer cools the mercury thread breaks at this point, leaving the column in the tube as it was at the highest temperature while in contact with the body. Thus the reading of the instrument may be made sometime after the temperature is taken. Before this thermometer can be used again, the mercury in the stem must be forced down into the bulb by giving the instrument a jerking motion.



MEASUREMENT OF HEAT

195. Distinction between Temperature and Quantity of Heat. It is important that a distinction be made between the temperature of a body and the quantity of heat which it contains. For example, a tin cup of boiling water has a temperature very much higher than that of the water in a lake under ordinary summer conditions, yet the quantity of heat in the water of the lake is many times greater than that of the cup. The temperature of a body depends on the average kinetic energy of its molecules; the quantity of heat in the body depends not only upon its temperature, but also upon its mass.

196. Unit Quantity of Heat. There are two units employed in the measurement of heat: (a) the calorie, based on the gram mass and the Centigrade scale, and (b) the British thermal unit

FIG. 161

(B.T.U.), based on the pound mass and the Fahrenheit scale.

✓ *A calorie is the quantity of heat required to raise the temperature of one gram of water one degree Centigrade.* Thus the quantity of heat required to raise one liter of water (1000 grams) from 20°C. to the boiling point (100°C.) is $1000 \times 80 = 80,000$ calories.

✓ *A British thermal unit (B.T.U.) is the quantity of heat required to raise one pound of water one degree Fahrenheit.* For example, the number of B.T.U. required to raise one gallon of water (8 pounds) from 70°F. to the boiling point (212°F.) is $8 \times 142 = 1136$ B.T.U.

197. Specific Heat. All bodies do not have the same capacity for heat. If we take one pound of water and one pound of iron and raise the temperature of each one degree, it will be found that while the water will require one unit of heat, the iron will require only about one-tenth of a unit. *The specific heat of a substance is the number of units of heat required to raise the temperature of unit mass one degree.* The specific heat of water is 1; that is, it requires 1 calorie to raise 1 gram 1°C. ; or in English units, it requires 1 B.T.U. to raise 1 pound 1°F. When we say that a substance, as mercury for example, has a specific heat of 0.033, we mean that it requires 0.033 of a unit (calories or B.T.U.) to raise the temperature of unit mass (gram or pound) one degree (Centigrade or Fahrenheit).

198. How to Find the Specific Heat of a Body. *Experiment.* One of the simplest means of determining the specific heat of a body is known as the *method of mixtures*. A hot body is brought in contact with a cooler body; the hot body loses heat and the cool body gains heat. Suppose that we wish to find the specific heat of lead. Put 200 grams of lead shot into a test tube and close the mouth of the tube loosely with a plug of cotton. Suspend the tube for several minutes in boiling water until the lead comes to the temperature of the water, which should be determined by means of a thermometer. Have at hand

a beaker containing a known mass of water, 200 grams say. Determine the temperature of this water, and then quickly transfer the shot from the test tube to the beaker. Stir gently with a thermometer until the mixture in the beaker (shot and water) comes to a constant temperature, which should be noted. We now have the following data: The mass of the lead and its change (fall) in temperature; the mass of the water and its change (rise) in temperature. From this we may compute the specific heat of the lead.

The calculation of the specific heat of a body by the method of mixtures is based on the assumption that the heat lost by one body is equal to the heat gained by the other body; that is, in the particular case under consideration, the heat lost by the lead is equal to the heat gained by the water. Now the heat lost or gained by the body, measured in calories or B.T.U., is equal to the mass of the body times the change in temperature, times the specific heat; therefore, we may write

$$\begin{aligned} \text{heat lost by lead} &= \text{heat gained by water}; \text{ that is,} \\ \text{mass lead} \times \text{ch. tem.} \times \text{sp. h.} &= \text{mass water} \times \text{ch. tem.} \times \text{sp. h.} \\ m \times t \times s &= m' \times t' \times s' \end{aligned}$$

in which m is the mass of the body losing heat, t its change in temperature, s its specific heat; and m' the mass of the body gaining heat, t' its change in temperature, s' its specific heat. This last equation expresses in a general and very convenient manner the relation of the heat lost to that gained, and enables us to determine any one of the six factors, provided five are given.

Example. To find the specific heat of lead from the following data: Mass of lead, 200 grams; temperature of the lead in hot water, 98°C. ; mass of water in the beaker, 200 grams; temperature of water before lead was put into the beaker, 20°C. ; final temperature of water, 22.3°C. *Solution:* Assuming that the heat lost by the lead is equal to the heat gained by the water, we may write

$$m \times t \times s = m' \times t' \times s'$$

$$200 \times (98 - 22.3) \times s = 200 \times (22.3 - 20) \times 1$$

$$s = 0.03$$

Example. In the preceding example it was assumed that all the heat lost by the lead was gained by the water, no account being taken of the heat absorbed by the beaker. In making accurate determinations of specific heat, however, it is always necessary to calculate the amount of heat absorbed by the containing vessel, as illustrated by the following: Suppose that an iron ball of mass 52 grams having a temperature of 100°C . be dropped into 200 grams of water at 20°C ., contained in a copper calorimeter having a mass of 100 grams. The resulting temperature of the calorimeter and its contents is 22.2°C . The specific heat of copper is 0.09. Find the specific heat of the iron. *Solution:* In making a calculation of this sort we assume that the heat lost by the iron is gained by the water and the calorimeter together; therefore, we may write

$$m \times t \times s = m' \times t' \times s' + m'' \times t'' \times s''$$

$$52 \times 77.8 \times s = 200 \times 2.2 \times 1 + 100 \times 2.2 \times .09$$

$$s = 0.113$$

EXERCISES. 3. A piece of nickel having a mass of 114 grams at 100°C . is dropped into 100 grams of water at 10°C . The resulting temperature of the water is 20°C . Find the specific heat of the nickel, neglecting the heat lost to the containing vessel.

4. One kilogram of water and one kilogram of iron, each at a temperature of 100°C ., are cooled to 20°C . How much heat in calories is given out by each?

5. A person drinks 300 grams of ice water which comes to the temperature of the body (98.5°F .). How many calories of heat are taken up by the water?

For Table of Specific Heats, see Supplement, 605.

EXPANSION

199. Expansion of Solids. When a solid is heated it, in general, expands; when cooled, it contracts. There are a few

exceptions to this rule, as for example, stretched india rubber and iodide of silver, both of which, within a certain range, contract when heated.

Experiment. If a metal rod be adjusted as shown in Fig. 162 and heat applied by means of a Bunsen burner, the rod will lengthen, causing the pointer to rotate, as the free end of the rod rolls over the needle. The increase in length due to a rise in temperature is called linear expansion.

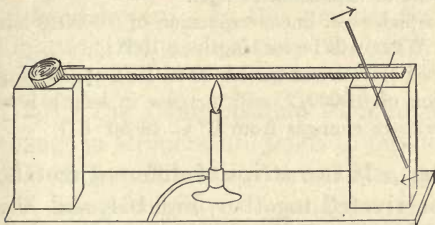


FIG. 162



FIG. 163

Experiment. The ring and ball experiment, Fig. 163, illustrates the fact that solids on being heated increase in volume. When both the ring and the ball are of the same temperature the ball passes readily through the ring. When the ball is heated it will not pass through the ring. The increase in volume due to a rise in temperature is called cubical expansion.

200. Coefficient of Expansion. All solids do not expand equally for the same change in temperature. For example, for a given change of temperature a brass rod will expand more than will a similar copper rod; and copper, in turn, will expand more than iron. It is important, then, to know something of the rate at which metals expand for given changes of temperature, the ratio expressing such expansion being called the coefficient of expansion. *The coefficient of linear expansion of a substance is its increase in length per degree per unit of length.* This may be written

$$\text{Coefficient of linear expansion} = \frac{\text{increase in length}}{\text{original length} \times \text{ch. tem.}}$$

Example. A metal rod 1 meter in length expands 2 millimeters when its temperature is increased from 0°C. to 120°C. Find its coefficient of linear expansion.

$$\text{Solution: } C. \text{ of } L.E. = \frac{0.2}{100 \times 120} = \frac{1}{60,000}$$

EXERCISES. 6. At a temperature of 0°C. an iron pipe is 100 ft. long. Its length increases to 100.12 ft. when heated to 100°C. by steam passing through it. Find the coefficient of expansion of iron.

7. A brass rod having a coefficient of linear expansion of 0.000018 has a length of 180 cm. at 0°C. What will be its length at 100°C. ?

8. A steel rail, such as is used on railroad tracks, 30 ft. long and having a coefficient of linear expansion of 0.000012, will increase in length how many inches when the temperature changes from 0°C. to 50°C. ?

201. The Compound Bar. If two strips of different metals, such as brass and iron, be riveted together, Fig. 164, and the compound bar thus formed be heated, it will bend in the form shown in *b*, due to the fact that the coefficient of expansion of brass is greater than that of iron. Some of the applications of the compound bar principle are illustrated in the following topics.

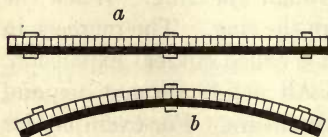


FIG. 164

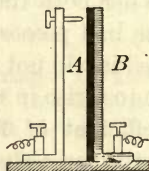


FIG. 165

202. The Alarm Thermometer. In Fig. 165 there is shown a device for automatically closing an electric circuit by the bending of the compound bar *B*. If the bar be heated, the brass will expand more rapidly than the iron, and thus cause the bar to bend toward *A* until electric contact is made. Such a device is sometimes used to give alarm in case of fire.

203. The Compound Balance Wheel. The balance wheel of a watch serves the same purpose as the pendulum in a clock.

If the temperature increase, the length of the spokes change thereby, and also the elasticity of the hairspring, causing a change in the period of vibration. To offset this change in the rate of vibration the rim of the wheel is made of a compound bar, the metals of which are arranged in such a way that the outer one expands much more rapidly than the inner one, thus causing the ends *A* and *B*, Fig. 166, to bend inward. In this manner the time of vibration of the wheel may be kept practically constant.

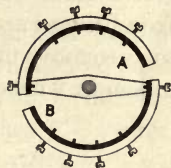


FIG. 166

204. The Compensation Pendulum. We have seen that a change in temperature tends to produce a change in the length of a body. Now any variation in the length of its pendulum will change the rate of a pendulum clock. Several devices, Fig.



FIG. 167

167, have therefore been employed to keep the length constant, one such being the so-called gridiron pendulum, in which the lengthening of the rods marked *s*, usually of steel, tends to lower the bob, while the expansion of the rods *b*, usually of brass, raises the bob, and thus the expansion of one set of rods is made to counteract the effect of the other. In the mercury compensating pendulum the lengthening or shortening of the rod is counteracted by a rise or fall of the center of gravity due to the expansion of the mercury in the two glass vessels forming the bob.

205. Further Applications of the Principles of Expansion. The fact that metals expand when heated and contract when cooled has to be taken into account in a great many building and engineering operations. For example, in the construction of a railway track, space must be left between the ends of the

rails to accommodate the expansion due to a change of temperature of about 50°C . from winter to summer.

Expansion joints are sometimes fitted into steam pipes to give some freedom of motion as the pipe expands and contracts. Iron bridges are sometimes left free at one end and constructed so as to move upon a roller, as the material of the bridge changes in length with change of temperature, Fig. 168.

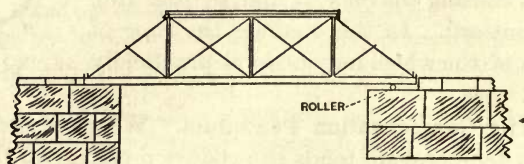


FIG. 168

206. The Force of Expansion and Contraction. The force exerted by metals when expanding or contracting is usually very great. It is estimated



FIG. 169

that it would require a pressure of nearly 10,000 pounds per square inch to keep mercury from expanding when heated from 0°C . to 10°C . Tires are heated and then slipped upon wagon wheels, Fig. 169. In cooling, the tire grips the wheel with a great force. Boiler plates

are also fastened together by heated rivets; when the rivets cool they contract, forming very tight joints.

207. Expansion of Liquids. Liquids in general expand when heated and contract when cooled. Since liquids conform to the shape of the containing vessel, it follows that in determining their coefficients of cubical expansion, account must be taken of

the expansion of the vessel as well as that of the liquid. Like solids, liquids have different coefficients of expansion. For example, the coefficient of expansion of alcohol is about 0.00104; that of mercury, 0.000182.

208. Anomalous Expansion of Water. Water is a partial exception to the rule that liquids expand when heated and contract when cooled. If a quantity of water at 0°C. be heated, its volume decreases until the temperature reaches 4°C. , after which the volume increases as the temperature rises, at 8°C. the volume being about the same as at 0°C. *At 4°C. , therefore, a given quantity of water has its least volume, and hence its greatest density.* This fact is of great importance in nature, as is illustrated by the freezing of water in a lake in winter. When the temperature falls, the water at the surface reaches its maximum density at 4°C. and sinks to the bottom, thus forcing the warmer water upward. This goes on until the entire lake reaches a temperature of 4°C. , after which the temperature of the water at the surface falls to 0°C. and begins to freeze. Since the density of ice is less than that of water at the freezing point, it remains at the surface. The temperature of the water at the bottom of a pond or a lake in winter is, therefore, 4°C. ; indeed, the temperature of the deep water of our great lakes remains at about this point throughout the year.

✓ **209. Expansion of Gases.** With respect to their expansion, gases differ from solids and liquids in two very important particulars. (a) For a given change of temperature, the expansion of gases is much greater than that of solids or liquids under ordinary conditions; (b) all gases have practically the same coefficient of expansion.

The coefficient of expansion of a gas is $\frac{1}{273}$. That is, if the temperature of a given volume of gas at 0°C. , and under constant pressure, be increased 1°C. , it will expand $\frac{1}{273}$ of its volume; if it be heated 10° it will expand $\frac{10}{273}$, and so on, the expansion in each case being calculated with reference to the volume at 0°C. If the gas be cooled, the pressure remain-

ing constant, it will contract $\frac{1}{273}$ of its volume at 0°C. , per degree.

210. Absolute Temperature. If a gas enclosed within a vessel of constant volume be heated, the pressure which it exerts will increase; if the gas be cooled, the pressure will decrease. The pressure exerted by a gas at 0°C. is changed $\frac{1}{273}$ per degree of change of temperature. Thus it will be noted that the pressure coefficient is the same as that of the volume coefficient, namely, $\frac{1}{273}$. Now, suppose that the temperature of this gas could be reduced 273° below 0°C. , it is evident that its pressure would become zero; which would mean that its molecular motion would also be zero. Since heat is due to molecular motion, it follows that under these conditions there would be no heat. This temperature, 273° below 0°C. , is called the *absolute zero*, and a scale based on this zero is called the *Absolute scale*.

Readings on the Centigrade scale may be changed to those on the Absolute scale by simply adding 273 to the C. values.

Example. Change the following Centigrade readings to Absolute: (a) 0°C. ; (b) $+20^{\circ}\text{C.}$; (c) -20°C. *Solution:* (a) $0^{\circ}\text{C.} = 0 + 273 = 273^{\circ}\text{Abs.}$; (b) $+20^{\circ}\text{C.} = 20 + 273 = 293^{\circ}\text{Abs.}$; (c) $-20^{\circ}\text{C.} = -20 + 273 = 253^{\circ}\text{Abs.}$

EXERCISES. 9. Give the absolute values for the following Centigrade readings: (a) $+10^{\circ}\text{C.}$; (b) -10°C. ; (c) boiling point on C. scale.

10. Give the equivalent Centigrade values for the following readings on the Absolute scale: (a) 243°Abs. ; (b) 303°Abs. ; (c) 0°Abs.

211. Gay-Lussac's Law. The law of Gay-Lussac, often called the law of Charles (Supplement, 561), takes its name from Gay-Lussac, a French physicist, who was one of the first to announce the law governing the relation between the volume and the temperature of a gas under constant pressure. This law may be stated as follows: *Under constant pressure the volume of a gas is proportional to its absolute temperature.* The law may be written

$$v : v' = T : T'$$

in which v and v' represent the volumes and T and T' the corresponding temperatures on the Absolute scale.

Example. A mass of gas having a volume of 100 cc. at $+20^{\circ}\text{C.}$ will have what volume at -20°C. , the pressure remaining constant? *Solution:* $+20^{\circ}\text{C.} = 293^{\circ}\text{Abs.}$ and $-20^{\circ}\text{C.} = 253^{\circ}\text{Abs.}$; hence we may write

$$\begin{aligned} 100 : v' &= 293 : 253 \\ v' &= 86.3 \text{ cc.} \end{aligned}$$

EXERCISES. 11. The volume of a given mass of gas under constant pressure at 27°C. is 500 cc. What will be its volume at -13°C. ?

12. A gas having a volume of 1000 cc. at -10°C. is heated and expands under constant pressure to 1200 cc. Find the resulting temperature.

CHANGE OF STATE

212. Fusion and the Melting Point. *Fusion* or melting is the process by which a solid changes to a liquid upon the application of heat. The melting of ice, sealing wax, glass, lead, etc., are all familiar examples of fusion. The temperature at which melting occurs is called the melting point.

Many substances like sealing wax, wrought iron, and most kinds of glass have no definite melting point. When heat is applied to such substances, they gradually soften to the point of liquefaction, the change from the solid to the liquid state at no instant being well defined.

Crystalline substances, such as ice, sulphur, cast iron, and most crystalline salts have definite melting points. For example, if a piece of ice at -10°C. be heated, the temperature will rise until it reaches 0°C. , at which point the ice will melt. The change from the solid to the liquid state, that is, from ice to water, is abrupt, and takes place at 0°C. Likewise, if water be cooled to this temperature, it freezes. The freezing point and the melting point are thus the same, 0°C. marking the dividing line between the solid and the liquid state.

213. Laws of Fusion. The principal facts relating to the fusion or melting of crystalline solids may be expressed by the following laws:

I. *For crystalline substances, the freezing point and the melting point are the same.*

II. *Every crystalline substance has a definite melting point for a given pressure.*

III. *When a crystalline substance reaches its melting point its temperature remains constant until it is entirely melted.* Thus, when a piece of ice begins to melt, its temperature remains at zero until it is all melted, no matter what the temperature of the water in which it may be placed.

For Table of Melting Points, see Supplement, 601.

214. Heat of Fusion. When a crystalline substance on being heated reaches the melting point, its change from the solid to the liquid state takes place without any rise of temperature. This change, however, requires heat. This heat which is consumed in changing the state of a body without changing its temperature is called the *heat of fusion, which may be defined as the heat required to change unit mass of a crystalline substance from a solid to a liquid without changing its temperature.*

The heat of fusion of ice is 80 calories per gram. That is, 80 calories of heat are required to change 1 gram of ice at $0^{\circ}\text{C}.$ to water at the same temperature.

215. Change of Volume during Fusion. Substances, in general, contract when they solidify and expand when they melt. Thus if molten lead be poured into a bullet mold and there solidify, it will be found that the bullet does not quite fill the mold; the lead contracts on solidifying and expands on melting. Certain highly crystalline substances, on the other hand, such as ice, cast iron, and type metal, expand when they solidify and contract when they melt. Such substances as cast iron (Art. 163) and type metal are suitable, therefore, for molding, since they expand on solidifying and thus fill every part of the mold and reproduce every detail of the pattern.

216. Water Expands on Freezing. It is estimated that 917 cc. of water on freezing will become 1000 cc. of ice. A cubic centimeter of ice is therefore lighter than a cubic centimeter of water, and hence floats. The pressure exerted by water in freezing is very great, as is often illustrated by the freezing and bursting of water pipes in winter. A cast iron bomb when filled with water and sealed and placed in a freezing mixture will explode with a loud report. This expansion of water in freezing plays an important part in the disintegration of rocks in the formation of soil.

217. Relation of Pressure to Fusion. *Experiment.* Pressure applied to a substance which contracts on melting, as ice for example, lowers the melting point. *Ice may be melted by applying a sufficiently high pressure to it.* Let a fine wire carrying a weight be passed over a small block of ice, as shown in Fig. 170. The ice just below the wire is melted by the pressure, the water thus formed passing above the wire and freezing again on being released. Thus in a short time the wire will cut its way through the ice, leaving the block as solid as before.

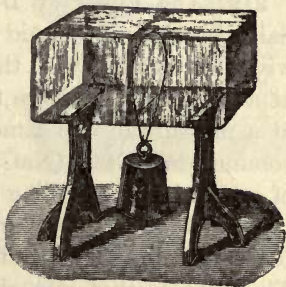


FIG. 170



FIG. 171

If the temperature be near the freezing point, wet snow may be packed into "ice balls," as every school-boy knows. Also two pieces of ice may be frozen together under warm water by applying considerable pressure and then releasing them suddenly, Fig. 171.

218. Boiling. If heat be applied to a kettle of water the following facts may be observed: (a) First, small bubbles of steam are formed at the bottom, and, as they rise, condense, the walls of the bubbles meeting with a sharp impact and thus

giving rise to the phenomenon known as "singing." (b) When the temperature of the water rises sufficiently high so that the vapor throughout the liquid has a pressure equal to or greater than that of the atmospheric pressure upon the surface, bubbles form copiously at the heating surface and rise to the top of the liquid, producing the agitation called boiling. (c) When the temperature reaches the boiling point it remains constant until the water all boils away.

Each liquid has a definite boiling point which is constant for constant pressure.

For Table of Boiling Points, see Supplement, 602.

219. The Effect of Dissolved Salts on the Boiling Point. Salt dissolved in a liquid raises its boiling point. Most housewives are familiar with the fact that water containing salt boils at a higher temperature than that which is pure. Pure water at a pressure of one atmosphere boils at 100°C . If, however, common table salt (NaCl) be added to the water to the point of saturation, the boiling point may be raised to 109°C .

220. Effect of Pressure on the Boiling Point. The boiling point of a liquid depends upon the pressure exerted upon it. The bubbles that give rise to boiling cannot form in a liquid unless they exert a pressure greater than that of the atmosphere. Therefore, if the pressure upon a liquid be increased, the boiling point is raised; increasing the pressure raises the boiling point; decreasing the pressure lowers the boiling point.



FIG. 172

Experiment. Put some water at room temperature and atmospheric pressure into a flask, and then connect the flask to an air pump (Supplement, 562), as shown in Fig. 172. A few strokes of the pump will be sufficient to reduce the pressure so that the water will boil vigorously. This experiment may be performed in another manner as follows: Heat the water in a flask to the boiling point and allow it to cool to 60 or 70°C ., then cork and invert the flask as shown in

Fig. 173. Now if water be poured upon it, thus condensing the vapor in the flask and thereby reducing the pressure, the water will boil.

In the manufacture of sugar, vacuum pans are used in which the boiling point of the syrup is lowered by reducing the pressure, thus avoiding the danger of burning the sugar. On the other hand, in the extraction of glue from bones, the pressure is increased and the boiling point of the liquid correspondingly raised.

221. Relation of Altitude to Boiling Point. Since atmospheric pressure decreases with the elevation, the boiling point of a liquid also decreases. The boiling point of water may therefore be used to indicate the height of a place above the sea level. A decrease of 1°C . in the boiling point indicates an elevation of 295 meters, or about 968 feet.

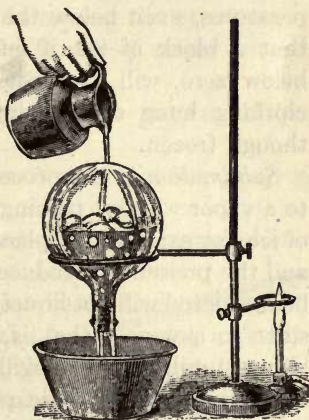


FIG. 173

EXERCISE. 13. The boiling point of water at sea level is 100°C .; on Pike's Peak it is 85.4°C . Find the elevation of Pike's Peak above sea level.

222. Laws of Boiling. The facts with respect to boiling as presented in the preceding topics may be summarized briefly in the following laws:

I. *Every liquid has a definite boiling point which is invariable under the same conditions.*

II. *An increase of pressure raises the boiling point; a decrease of pressure lowers the boiling point.*

III. *Salts dissolved in a liquid raise the boiling point; gases dissolved in a liquid lower the boiling point.*

223. Vaporization. The process by which a substance

changes to a vapor is called *vaporization*. It may take place by boiling, by evaporation, or by sublimation.

Evaporation is the process by which a liquid changes quietly at the surface to the vapor state. It takes place at all temperatures, even below the freezing point. It has been found that a block of ice, if left for a few days at a temperature below zero, will lose considerably in weight by evaporation; clothing hung out to dry on a cold winter's day will dry though frozen.

Sublimation is the process by which a solid changes directly to a vapor without passing through the liquid state. If a piece of ice, for example, be placed under the receiver of an air pump, and the pressure be reduced to 4 millimeters or less, the ice on being heated will not liquefy, but will pass directly from the solid state to a vapor; that is, it will sublime. If the pressure be above 4 millimeters, it will liquefy. Camphor and arsenic will sublime at atmospheric pressure. These substances may be liquefied by sufficiently increasing the pressure upon them. Since arsenic sublimates at atmospheric pressure it is considered detrimental to health to use wall paper which contains any considerable amount of arsenic in the coloring matter.

224. Rate of Evaporation. The rate at which evaporation goes on depends upon four factors: (a) The extent of the free surface of the liquid; (b) the temperature; (c) the pressure exerted upon the surface of the liquid; (d) the degree of saturation of the space above the liquid.

It is a familiar experience that if a given quantity of water be placed in a broad shallow dish it will evaporate much more quickly than if placed in a deep narrow dish; and also that the higher the temperature, the more rapid is the rate of evaporation. The drying of roads and streets after a rain illustrates the effect of a change of air on the rate of evaporation. If after a rain there be no wind, the air soon becomes saturated and evaporation is retarded; if, however, the air be in motion, evaporation goes on rapidly and the roads

soon become dry. Damp clothes hung out to dry on a windy day also illustrate the case in point.

The rapid evaporation of liquids in "vacuum pans" due to diminished pressure is an application of the principle that the rate of evaporation is increased by decreasing the pressure.

225. Laws of Evaporation. I. *The rate of evaporation increases with the free surface of the liquid.*

II. *The rate of evaporation increases with increase of temperature.*

III. *The rate of evaporation increases with a change of air in contact with the liquid.*

IV. *The rate of evaporation increases as the pressure diminishes.*

226. Heat of Vaporization. If heat be applied to water the temperature rises until it reaches the boiling point. Further application of heat produces no further rise of temperature, the additional heat being used in changing the water from the liquid to the vapor state. *Heat of vaporization is the heat required to change unit mass of a substance from the liquid to the vapor state without changing its temperature.* The heat required to change one gram of water at 100°C. to steam at the same temperature is 538 calories; hence we say that *the heat of vaporization of water at 100°C. is 538 calories per gram.*

The high heat of vaporization of water explains the value of steam heat as a means of heating buildings. Every gram of steam that changes from steam at 100°C. to water at the same temperature gives up 538 calories of heat.

227. Vapor Pressure. When a liquid evaporates into the space above it, the vapor thus formed exerts a pressure which is known as the *vapor pressure* of the liquid at that temperature. Each liquid has its own definite vapor pressure for a given temperature. *Experiment.* If a tube 80 centimeters in length be filled with mercury and inverted in a dish of mercury, Fig. 174, a Torricellian vacuum, *v*, results. Now introduce into this tube at the bottom, by means of a glass rod or pipette, a few

drops of water, w , which being lighter than the mercury rise in the tube to the surface, and a portion of it evaporates. The water vapor thus liberated in the space above the mercury exerts a

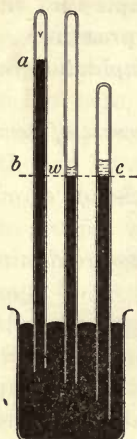


FIG. 174

pressure (the vapor pressure of water) which forces the column of mercury down to a certain point, b . The difference between the height of the column a and that of b represents in centimeters the vapor pressure of water at the given temperature. Now if the tube be forced down into the mercury as shown in c , some of the vapor will liquefy, but the mercurial column will stand at the same level as before. The vapor pressure of a liquid is the same whether the space above the mercury be great or small, provided there is some free liquid present.

228. Water Vapor in the Air. There is in the air at all times a certain amount of water vapor. At 20°C . (68°F .) a cubic meter of space when saturated contains about 17 grams of water vapor. The presence of air in the space does not appear to affect the amount of water vapor which it can contain. That is, a cubic meter of space at 20°C . will contain 17 grams of water vapor, whether it contain air at the same time or not.

229. Humidity. *Humidity* is a term used to indicate the quantity of water vapor in the air. When the air contains all the water vapor it can at a given temperature it is said to be saturated. At 20°C . air is saturated when it contains 17 grams of water vapor per cubic meter.

Relative humidity is the ratio of the amount of water vapor in the air at a given time to the amount that would be present if it were saturated. Relative humidity is usually expressed in terms of per cent; thus when we say that the relative humidity is fifty, we mean that the air contains 50 per cent of the water required to saturate it at that temperature.

For Humidity Tables, see Supplement, 606.

Example. On a given day when the temperature was 23°C . it was found that the air contained 14.25 grams of water vapor per cubic meter. Find the relative humidity. *Solution:* On consulting the table found in the Supplement, 606, we find that air at 23°C . is capable of holding 20.355 grams of water vapor per cubic meter. The relative humidity, therefore, is $\frac{14.25}{20.355} = 70$ per cent.

EXERCISE. 14. A given quantity of air at 20°C . contains 10.2 grams of water vapor per cubic meter. What is the relative humidity?

230. Relation of Humidity to Bodily Comfort. The temperature of the human body remains very nearly at a constant temperature of 98.5°F . In order to keep the temperature thus uniform, free evaporation from the surface of the body must be maintained. This is especially true in warm weather. Evaporation is a cooling process; when it goes on freely the temperature is lowered; when it is retarded the temperature rises. Now when the air is filled with moisture, that is when the relative humidity is high, evaporation is retarded; hence the temperature of the body tends to rise. If the air be dry, that is, the relative humidity low, evaporation is accelerated and the body remains cool, even though the temperature of the air be high. Men working in the stoke hole of a ship where the temperature is very high are able to maintain their vigor because of the fact that a draft of air is forced through the room in which they work, thus stimulating rapid evaporation from their bodies. If the air in the stoke hole were allowed to become highly charged with vapor, it would be impossible for them to perform their task. It has been observed that the greatest number of fatalities due to heat prostrations in the summer time occur not always when the temperature is highest, but on those days when the relative humidity is greatest.

231. Humidity in Artificially Heated Rooms. Suppose the outdoor air in winter has a temperature of 0°C . and a relative

humidity of 80 per cent. Now, since a cubic meter of air at 0° C. is capable of containing 4.8 grams of water vapor (Supplement, 606), a humidity of 80 per cent would represent $\frac{80}{100} \times 4.8 = 3.84$ grams per cubic meter. If this air on entering a building be heated to 20° C. (68° F.), each cubic meter will be capable of containing 17 grams of water vapor. Its relative humidity will thus be lowered to $\frac{3.84}{17} = 22.6$ per cent. For health and comfort, however, air should possess a relative humidity between 50 and 60 per cent. It is evident, therefore, that unless some special provision be made for adding moisture to the air when thus heated, the humidity will be far too low. All buildings heated by stoves, hot air furnaces, or steam radiation should have some means of supplying to the air a sufficient quantity of water vapor to bring the humidity up to the required standard. To accomplish this there is usually placed in connection with the ordinary furnace a water pan, which should be kept filled in order to supply to the dry warm air entering the room a requisite amount of water vapor.

232. Dew Point. Experiment. Place a thermometer in a test tube partly filled with ether, Fig. 175. By means of a bent glass tube blow gently through the liquid a stream of air bubbles which will cause the ether to evaporate rapidly, thus



FIG. 175

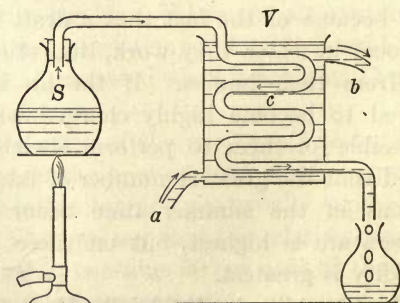


FIG. 176

producing a fall in temperature, as indicated by the thermometer. As the temperature falls, a point will be reached at which moisture or dew, condensed from the surrounding air, will appear on the outside of the tube. *The temperature at which this moisture appears is called the dew point. The dew point is the temperature at which the water vapor of the air reaches saturation and begins to condense.* Suppose, for example, that the air on a given day when the temperature is 20°C . contains 12.7 grams of water vapor per cubic meter. Now it has been found by experiment (Supplement, 606) that the saturation temperature for 12.7 grams per cubic meter is 15°C . This means that if the temperature of the air fall to 15°C ., water will be precipitated in the form of dew. In other words, for 12.7 grams of water vapor per cubic meter, 15°C . marks the dew point. Fogs, clouds, and rain result from a lowering of the temperature below the dew point.

233. Distillation. *Distillation* is a process of separating one liquid from another or of separating a liquid from impurities by heating the mixture in one vessel and condensing the vapor in another. One form of distilling apparatus is shown in Fig. 176. Suppose that some water be placed in the vessel *S*, called the still, and heated. The vapor passes through the coiled tube called the worm. The vessel *V* is filled with cold water entering at *a* and leaving at *b*, which condenses the vapor in the coil *c*, from which the pure water drops into the receiver *R*. The liquid which is collected in this receiver is called the distillate.

By means of this process of distillation pure water may be obtained from impure, and also one liquid may be separated from another, as for example, commercial alcohol from water, in which case alcohol, being the more volatile, distils over more readily than the water. Mercury is often distilled in order to separate it from its impurities.

COLD BY ARTIFICIAL MEANS

234. The Principle. The production of cold by artificial means is today of great commercial importance. There are three methods of producing cold artificially; namely, (a) by solution; (b) by evaporation; (c) by expansion of gases. The fundamental principle involved in these three methods is the same; that is, each process involves the expenditure of energy, which in turn involves the absorption of heat. When, for example, salt dissolves in a liquid, or a liquid evaporates, or a gas expands, energy in the form of heat is taken up and a condition of cold is produced.

235. Cold by Solution. When a lump of sugar is dropped into a cup of coffee, the temperature of the coffee is lowered slightly as the sugar dissolves, due to the fact that the dissolving of the sugar takes energy from the liquid in the form of heat. In general the solution of crystalline substances in liquids tends to lower the temperature, although in some cases this lowering of the temperature is marked by secondary chemical reactions.

Experiment. If some salt (Supplement, 563) be put into a beaker of water at room temperature and stirred gently with a thermometer, it will be observed that the temperature of the water will fall several degrees. The dissolving of the salt takes energy from the water in the form of heat, thus causing the fall in temperature.

236. The Ice Cream Freezer. The common ice cream freezer

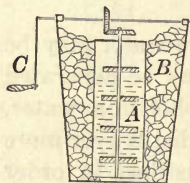


FIG. 177

is one of the best known devices for producing cold by artificial means. The principle employed is that of the production of cold by solution. The cream to be frozen is placed in a metallic vessel *A*, Fig. 177, in which a stirrer is rotated by means of the crank *C*. Around this vessel there is packed a mixture of salt and crushed ice, *B*. The contact of the salt with the ice tends to cause the latter to

melt, and the resulting liquid dissolves the salt, both operations requiring heat, which is withdrawn from the cream in the vessel A. The object of stirring the cream is to bring all portions of it successively in contact with the walls of the containing vessel, causing it to freeze uniformly. It is important to note that the cream freezes when the ice melts; that is, the melting ice absorbs heat which is furnished by the cream.

It has been found by experiment that the best mixture of ice and salt for producing a maximum lowering of temperature is three parts of ice to one part of salt by weight.

237. Cold by Evaporation. *Experiment.* When a liquid evaporates, energy in the form of heat is required to separate the molecules. Evaporation is therefore a cooling process. If some highly volatile liquid, as ether, be dropped upon the bulb of an air thermometer, Fig. 178, the colored liquid in the stem will quickly rise, due to the chill produced by the rapid evaporation of the ether, resulting in a contraction of the air within the bulb. Sprinkling the floor with water in summer cools the air in the room because of the heat absorbed by the evaporation of the water.



FIG. 178

Experiment. Fill a small porous battery jar with water and place in the vessel a thermometer, Fig. 179, noting the temperature at the beginning of the experiment. In the course of fifteen minutes the temperature of the water will have fallen considerably, due to evaporation from the sides of the jar. In some warm countries, as Mexico, water is often cooled by placing it in large porous vessels, which allow evaporation to take place over the entire surface.

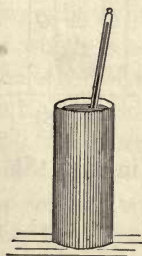


FIG. 179

238. Cold by Expansion. When a gas expands it does work on the surrounding medium; the energy thus expended comes from the gas in the form of heat, and as a

result the temperature is lowered. The cooling effect of an expanding gas may be strikingly illustrated in the following manner. Obtain a tank of liquid carbon dioxide, such as is

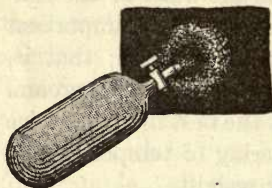


FIG. 180
Carbon Dioxide Snow

employed in connection with soda fountains. The carbon dioxide in the tank is under enormous pressure. If now the stop cock connected with the tank be opened and the gas within be allowed to expand, there will result a lowering of the temperature due both to the vaporization of the liquid and the

expansion of the gas. The chill produced is sufficient to freeze the carbon dioxide, which appears in the form of a white mist or snow, Fig. 180.

239. The Ice Machine. The principle of the ice machine may be illustrated by means of a very simple apparatus, as shown in Fig. 180. Two tanks *A* and *B* are connected by means of a short tube. Tank *A*, which contains some liquid ammonia, is placed in the water to be frozen; the piston in tank *B* is suddenly withdrawn, thus reducing the pressure. The liquid ammonia in *A* evaporates and expands into *B*, producing a chill, and thus tending to freeze the water in *C*. The lowering of the temperature is produced by both the evaporation and expansion of the ammonia. In actual practice the machine is very much more complicated than that shown in Fig. 181. (Supplement, 564.)

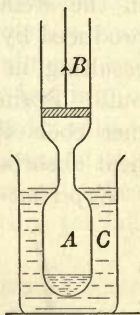


FIG. 181

TRANSMISSION OF HEAT

240. Modes of Transmission. Heat may be transmitted from one point to another in three ways: (a) by conduction, (b) by convection, and (c) by radiation.

Conduction is the transmission of heat through a body from molecule to molecule, as in the heating of a piece of iron in a flame. The heat is transmitted from one end of the iron to the other by conduction.

Convection is the transmission of heat by means of a current, as for example, winds and ocean currents. The Gulf Stream is an example of a convection current.

Radiation is a transfer of energy through space by means of waves set up in a hypothetical medium called the ether. The earth is thus heated by radiation from the sun.

241. Conductivity of Solids. Experiment. If one end of a piece of wire be held in a Bunsen burner, the heat is rapidly transmitted along the wire, which will soon become too hot to hold. Metals are in general good conductors. If now a glass rod be held in a flame as in the case of the wire, it will be found that the glass may be entirely melted only a few centimeters from the hand without the rod becoming too hot to hold. Glass is a poor conductor of heat. Again, a match may be burned until the flame almost touches the fingers, showing that wood is a very poor conductor of heat.

242. Relative Conductivity of Wood and Metal. Experiment. The relative conductivity of wood and metal may be shown by wrapping a piece of paper around a cylinder, Fig. 182, one end of which is composed of metal and the other of wood. If now the cylinder be held in a flame, the paper will char where it touches the wood, but will not be burned where it is in contact with the metal, due to the fact that the metal conducts the heat away so rapidly as to keep the paper below the burning point.

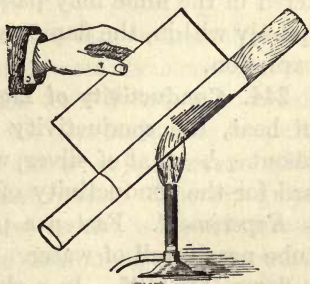


FIG. 182

243. Conductivity of Wire Gauze. Experiment. If a piece of wire gauze be held over a small flame, Fig. 183, the flame will

not pass through it. Also, if the gauze be placed a short distance above the burner and the gas turned on and lighted above the gauze, the flame will refuse to pass down to the burner. The metallic gauze conducts the heat away from the flame so rapidly that the gas on the opposite side in each case is not heated to the point of combustion.

This property of wire gauze is made use of in the construction of the Davy Lamp, Fig. 184, named after its inventor, Sir

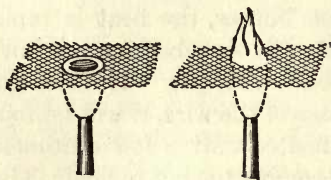


FIG. 183

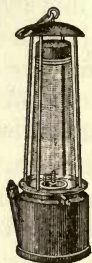


FIG. 184

Humphrey Davy. This device, which is often used by miners, consists of a small oil lamp, the flame of which is covered by a cylinder of wire gauze. While any inflammable gas encountered in the mine may pass freely through the gauze and burn quietly within, the flame cannot pass outward and so cause an explosion.

244. Conductivity of Liquids. Liquids are poor conductors of heat, the conductivity of water, for example, being only about $\frac{1}{1000}$ that of silver, which is sometimes taken as a standard for the conductivity of metals.

Experiment. Fasten a piece of ice in the bottom of a test tube nearly full of water. Hold the upper part of the tube in a flame, Fig. 185. In a short time the water in the top of the tube will begin to boil, thus giving boiling water, tepid water, and ice water all in the same vessel.

Experiment. The nonconducting property of water may be

very well illustrated by means of an apparatus shown in Fig. 186. An air thermometer is sealed into the stem of a funnel, which is then filled with water to within a few centimeters of the surface. Some ether is poured upon the surface of the water and is then set on fire. Notwithstanding the fact that the ether burns only a few millimeters above the bulb of the air thermometer, it will be observed that the colored liquid in the stem is not affected thereby, thus showing that practically no heat is conducted down through the water.

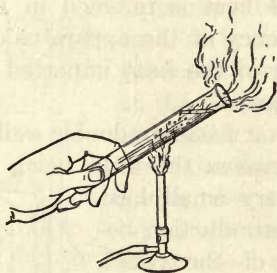


FIG. 185

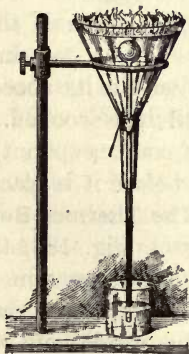


FIG. 186

245. Conductivity of Gases. Gases are extremely poor conductors of heat. Woolen clothing owes its nonconducting properties partly to the fact that the wool fibre is a poor conductor, but more largely because of the nonconducting property of the air enclosed within it. The fur of animals is an effective protection from cold for the same reason. The air spaces between double windows and between the walls of houses are also illustrations of some of the uses made of the nonconducting properties of gases.

246. The Fireless Cooker. Of recent years much use has been made of the principle of the nonconducting properties of gases in the construction of the so-called fireless cooker, Fig.

187. This device consists usually of a wooden box containing a number of receptacles designed to receive the food to be cooked. Around these vessels there is closely packed some

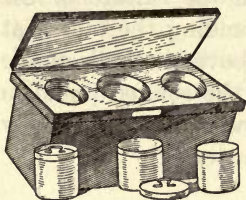


FIG. 187

material, such as hay, felt, asbestos, or other nonconducting material, which encloses within its interstices nonconducting air. The food to be cooked is heated to the boiling point and then placed in the receptacles within the cooker and carefully covered. Due to the nonconducting property of the packing material, and especially to the air

enclosed within its spaces, sufficient heat is retained in the food until it is cooked. The efficiency of the apparatus depends, of course, upon the retention of the heat imparted to the food before it is placed in the cooker.

247. The Thermos Bottle. A Dewar flask is a double walled glass vessel, Fig. 188, the space between the walls being an extremely low vacuum. Only a very small heat exchange, therefore, takes place by conduction between the inside and the outside of the vessel. Liquids with low boiling points such as liquid air or liquid oxygen may be kept much longer in Dewar flasks than in ordinary vessels. Recently such flasks enclosed in an outer covering of leather or metal have been placed upon the market under the name of "thermos" bottles, which serve equally well for keeping a liquid hot or cold. The nonconducting property of these vessels is due to the low vacuum between the double walls.



FIG. 188
Dewar
Flask

248. Convection. Convection is the transmission of heat by currents. An example of convection currents may be seen in the motion of water in a beaker when heated as shown in Fig. 189. Currents of hot air rising from radiators or furnaces are also convection currents.

An explanation of convection may be given somewhat as follows: When a given mass of a fluid, air or water, is heated, it expands and its density diminishes. The surrounding medium being the heavier, tends, therefore, to displace the warm and relatively light fluid, forcing it upward. As the warm current rises it carries heat with it. Thus it appears that a fluid which is heated does not rise of its own accord, but is forced upward by the colder and heavier medium surrounding it.

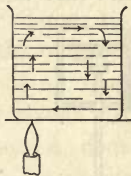


FIG. 189

249. Use of Convection Currents in Heating. *Experiment.*

Convection currents such as are used in hot water heating systems may be demonstrated by a simple device, such as is shown in Fig. 190. Fill the flask and tubes with water. Then add to the open vessel at the top, some colored liquid. Now when heat is applied to the lower vessel the cold water in the tube descends and the hot water rises, thus giving rise to convection currents, the colored liquid showing very clearly their direction. The lower vessel corresponds to the furnace, the tubes to the pipes and coils of the heating system, and the upper vessel to the expansion tank, which is usually located in an upper story of the house.

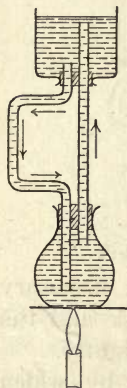


FIG. 190

In Fig. 191 there is shown a hot water heating system, and in Fig. 192 a hot water tank such as is used in connection with the ordinary furnace to provide hot water throughout the house.

250. Ventilation. *Experiment.* The fundamental principles governing ventilation may be illustrated by an experiment with a candle and a glass flask, Fig. 193. By means of a wire lower a small lighted candle into a flask having a rather wide neck. The flame burns brightly for a while, and then begins to grow dim, and soon goes out, due to the fact that the oxygen of the air within the flask is burned out. Now if a strip of

tin or cardboard be thrust down into the neck of the flask and be so adjusted that a stream of cool air will descend on one side and a stream of hot air ascend on the other, Fig. 194,

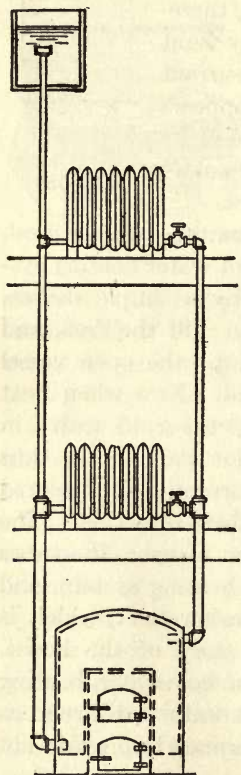


Fig. 191

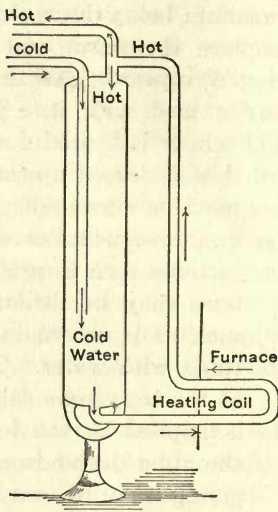


Fig. 192

we shall have the condition necessary for the ventilation of the flask and the candle flame will then burn brightly.

Ventilation is the process by which fresh pure air is supplied to rooms and buildings and impure air removed.

251. The Constituents of the Air. In order to discuss intelligently the subject of ventilation it will be necessary to consider briefly the composition of the air, and also the question of what constitutes pure and impure air. Air is composed of two gases, oxygen (O) and nitrogen (N), in the ratio of 1 to 4 by volume. In addition to oxygen and nitrogen, the air contains also a small proportion of a number of other substances,

such as water vapor, ozone, carbon dioxide, smoke, dust, germs, etc.

Oxygen is the life-giving principle of the air. It supports combustion, whether it be in the case of a candle flame, the burning of wood in a grate, coal in a furnace, or the combustion of the waste tissues of the body. *Nitrogen* is an inert gas which serves to dilute the oxygen and thus prevent too rapid combustion. If the air consisted of pure oxygen, combustion would go on at a destructive rate. It can be shown that in undiluted oxygen even iron will burn, Fig. 195. *Carbon*

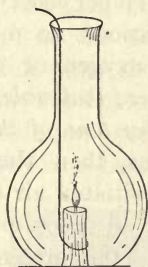


FIG. 193

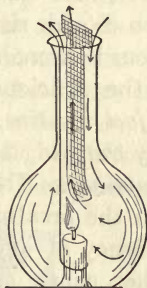


FIG. 194



FIG. 195.

dioxide is a non-poisonous gas and a non-supporter of animal life and combustion. If one were placed in a tank filled with carbon dioxide he would be smothered as effectively as if he were drowned in water. While carbon dioxide is not in itself poisonous, yet it is usually taken as the measure of the impurities present in the air of a room due to respiration and other exhalations from the body. If there be a relatively large quantity of carbon dioxide present in a room, it is assumed that the air is impure.

Pure air is air which is free from injurious gases or vapors, dust, and disease germs.

252. Test for Carbon Dioxide. *Experiment.* That carbon dioxide is given off from the lungs in respiration may be shown

by forcing some air from the lungs through a small glass tube into clear lime water contained in a test tube. When the carbon dioxide comes in contact with the lime water a white precipitate of calcium carbonate (CaCO_3) is formed. (Supplement, 565.) The degree of turbidity or milkiness of the lime water is taken as a test of the quantity of carbon dioxide present.

253. The Object of Ventilation. It is quite commonly believed that the main object of ventilation is to furnish a fresh supply of oxygen and to eliminate the carbon dioxide. Experiments have shown, however, that unless the oxygen fall below 12 per cent and the carbon dioxide rise above 3 per cent, conditions which very rarely occur in human habitations, no marked discomfort ensues from the deficiency of oxygen or excess of carbon dioxide. *The fact remains, however, that unless the air in a room be frequently changed, the healthy tone of the human body cannot be maintained.* This seems, then, that the ill effects which arise from the breathing of vitiated air comes not so much from a deficiency of oxygen or an excess of carbon dioxide as from other causes, such as the presence of injurious gases, infectious germs, faulty temperature, and moisture regulation, etc. *We ventilate, then, to supply fresh out-of-door air, and to remove impure air, and also to regulate temperature and moisture conditions.*

It is important to make a distinction between danger and comfort in the air conditions of a room. For example, a room cannot long remain comfortable that does not have some degree of ventilation; that is, it may be too hot or too cold, too dry or too moist.

It is estimated that the proper quantity of air that should be supplied to a room is about *2000 cubic feet per person per hour.*

254. Means of Securing Ventilation. Natural ventilation is that which takes place through the walls, cracks around doors, windows, etc., and through the opening and closing of

doors in passing from one room to another, Fig. 196. Except on windy days this method is not sufficient to keep the air of most rooms in proper condition for breathing, and especially is this true of rooms where large numbers of persons are congregated.

That a passage of air from room to room does actually take place may often be demonstrated, as shown in Fig. 197, by means of a candle flame. At the top of the door the flame is bent in one direction, at the bottom in another direction, thus showing that there is a draft of air into the room at the bottom and a draft out at the top.

Ventilation by means of hot air furnaces, in which pure out-of-door air is heated and then passed into the rooms through

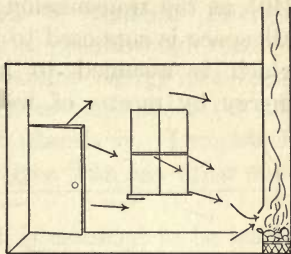


FIG. 196

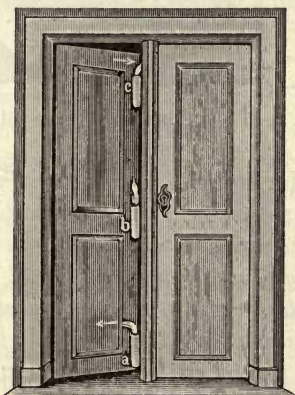


FIG. 197. — Inflow and Outflow of Air through Open Door

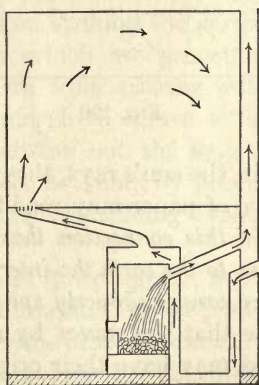


FIG. 198

registers, is a very good method of ventilating buildings which are not too large, Fig. 198. In large buildings, such as audi-

toriums, the most economical and efficient method of changing the air is by means of mechanically driven fans, Fig. 199.

255. Radiation. Radiation has already been defined (Art. 240) as the transmission of energy by means of ether waves. All space is supposed to be filled with a medium called ether, which is assumed to have the properties of transmitting energy by means of waves. This so-called radiant energy

may be focused by means of a lens, Fig. 200. If a lens, such for example as a common reading glass, be

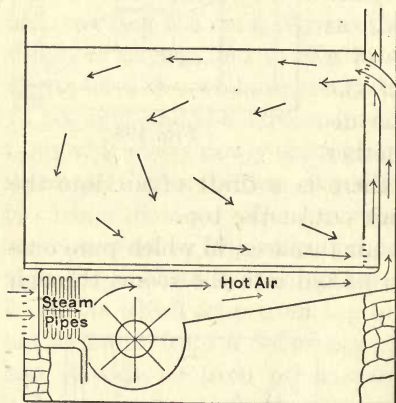


FIG. 199

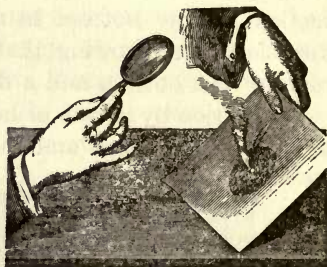


FIG. 200. — Burning Glass

held in the sun's rays, they will be brought to a focus in which a piece of paper may readily be set on fire. *It is important to note in this connection that in the transmission of energy from the sun to the earth the intervening space is not heated, and therefore we cannot properly speak of this radiant energy as heat.* It is true that the waves by means of which the energy is transmitted may have their origin in a heated body, the sun, and when they fall upon the earth they may give rise to heat, which is transmitted from point to point through the medium of matter by conduction or convection. It must not be thought, however, that the sun is the only source of radiant energy. All hot bodies may lose heat by conduction, convec-

tion, and radiation. The important point to be kept in mind is that radiation is a transference of energy, which when expended upon matter may give rise to heat.

256. Transmission and Absorption of Radiant Energy. Some substances allow radiant energy to pass through readily. Rock salt, for example, transmits radiant energy the most readily of any substance known. Other substances do not transmit radiant energy readily, but absorb it. Lampblack absorbs radiant energy to a greater degree than any other substance known.

Radiant energy, as has been stated, is assumed to be transmitted by means of ether waves, some of which are long and some short. Some substances like glass and water allow the short waves to pass through readily, but absorb the long waves. Radiant energy comes from the sun to the earth in the form of both long waves and short waves. Now the atmosphere surrounding the earth contains enormous quantities of water vapor, which transmits the short waves and shuts off the long waves. These short waves on striking the earth heat it, and then give rise to long waves, which are prevented by the water vapor in the atmosphere from passing out into space. Thus the water of the atmosphere serves as a sort of protecting blanket, which by shutting out the long waves keeps our days from being excessively hot, and, by preventing too rapid radiation, keeps our nights from being excessively cool.

The hot house has been called, and quite rightly, a trap to catch sunbeams. The short waves of radiant energy pass readily through the glass, and falling upon the interior heat it. Now the heat thus generated gives rise to long waves which cannot pass through the glass, their energy being thus entrapped, so to speak. That glass allows short waves to pass and not long waves may be seen when we consider the fact that the short waves conveying radiant energy from the sun pass readily through the glass of windows, and falling on our bodies give

rise to heat. On the other hand it is a well known fact that if a glass screen be placed in front of a grate fire it will effectively shut off the heat; that is, it will prevent the transmission of the long waves conveying radiant energy from the fire.

257. Illustrations of the Absorbing Power of Lampblack.

Experiment. To show that lampblack absorbs radiant energy to a greater degree than does glass, take two air thermometers as shown in Fig. 201 (Supplement, 566) and coat the bulb of one of them with lampblack from a candle flame. Adjust the colored liquid to about the same height in both stems. Now place a hot body such as a Bunsen flame or a sheet of hot iron midway between the bulbs. The radiation from the hot body passes quite readily through the glass bulb, but is absorbed by the blackened bulb, as is shown by the lowering of the colored liquid in the tube.

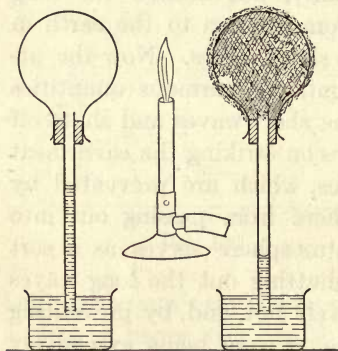


FIG. 201

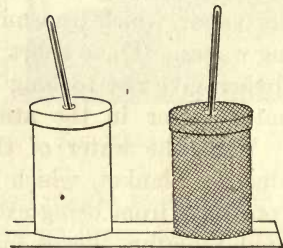


FIG. 202

258. Absorption and Reflection of Radiant Energy. The amount of radiant energy absorbed or reflected by a body depends upon (a) the temperature of the body and (b) the nature of its surface. In general a rough black body is a good absorber but a poor reflector of radiant energy; a smooth bright body is a poor absorber but a good reflector.

Experiment. To determine the relative radiating power of a black body as compared with that of a bright body. Take

two bright tin cans (baking powder cans from which the wrappings have been removed will do) and punch a hole in the cover of each for the admission of the thermometers, Fig. 202. Coat one of the cans heavily with lampblack. Fill both with hot water and note the temperature of each at the beginning of the experiment. After a time again observe the temperature of the water in each can. It will be found that the water in the black can is considerably cooler than that in the bright one. A rough black body radiates more readily than a smooth bright body.

Experiment. Again fill both cans with cold water and insert the thermometers. Place the cans in the sunshine, or at equal distances from a radiator. Note the temperature at the beginning of the experiment and at the end of half an hour. The water in the black can will be the hotter by several degrees. A rough black body is a better absorber of heat than is a bright polished body.

EXERCISES. 15. If a piece of black cloth and a piece of white cloth be placed in the sunshine upon the surface of snow in winter, which will settle into the snow the more rapidly?

16. Should cans used in shipping milk in summer be bright or dark in color, and why?

17. Which is the warmer in winter, a shoe that is polished or one that is not polished, other things being equal?

RELATION OF HEAT TO WORK

259. **Joule's Experiment.** The first accurate determination of the relation between heat and work was made in 1845 by Joule (1818 — 1889), an English physicist. His experiment was conducted somewhat as follows. A given quantity of water was placed in a vessel containing a paddle wheel, Fig. 203. About the axle of the wheel there was wound a strong flexible cord, to the end of which was attached a weight w . When the weight was allowed to fall, the work done, measured in foot pounds, was equal to the weight w in pounds

times the space s . The falling of the weight caused the paddles to rotate, thus doing the work upon the water and causing a rise in temperature. Joule's experiment demon-

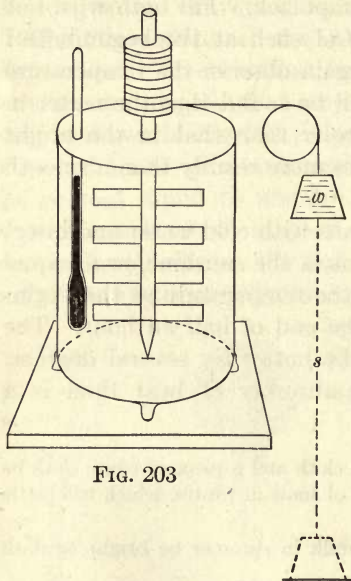


FIG. 203

strated that a weight of 77.2 pounds falling through a distance of 10 feet (772 F.P.) would raise the temperature of 1 pound of water 1° F. This means that a pint of water (1 pound) in cooling from the boiling point (212° F.) to room temperature (70° F.) would give out heat enough to do more than 100,000 foot pounds of work.

260. The Mechanical Equivalent of Heat. *The relation of work units to heat units is called the mechanical equivalent of heat.* In 1879 Professor Rowland of Johns Hopkins University made a series of classical experiments with an improved form of

Joule's apparatus, which determined the following values for the mechanical equivalent of heat:

$$1 \text{ calorie} = 4.19 \times 10^7 \text{ ergs}$$

$$1 \text{ B.T.U.} = 778 \text{ foot pounds}$$

261. Heat of Combustion. The heat of combustion of a substance is measured by the number of units of heat given out when unit quantity of the substance is burned. The heat of combustion of fuel such as coal and illuminating gas may be expressed in calories or in British thermal units (B.T.U.). It has been shown by experiment that the heat of combustion for coal of average grade and illuminating gas are about as follows:

1 pound coal = 15,000 B.T.U.

1 cubic foot illuminating gas = 600 B.T.U.

Coal is classified, with reference to the volatile matter that it contains, into bituminous or soft coal, semi-bituminous, and anthracite or hard coal. (a) A bituminous coal is one that contains over 20 per cent of volatile matter. This coal is used largely in the manufacture of gas. Hocking Valley coal is a type of bituminous coal of average grade having a heat of combustion of about 14,000 B.T.U. per pound. (b) Semi-bituminous coal looks something like anthracite, but is lighter in weight and burns more readily. It is valuable where it is necessary to keep an intense heat. A high grade semi-bituminous is that known as Pocahontas, the heat of combustion of which is 15,700 B.T.U. per pound. (c) Anthracite or hard coal contains less than 10 per cent of volatile matter. It ignites very slowly and burns at a high temperature. Owing to its smokeless burning it is used almost altogether for domestic purposes. A good quality of anthracite coal, such as Scranton coal, has a heat of combustion of about 13,800 B.T.U. per pound.

For Table of Heats of Combustion, see Supplement, 608.

262. The Heat Engine. The usual method of transforming heat into mechanical work is by means of the heat engine, as is illustrated by the steam engine of the railroad locomotive and the gas engine of the automobile. In the ordinary form of the steam engine, Fig. 204, steam under high pressure is admitted to the cylinder *C*, Fig. 205, first on one side and then on the other of the piston *P*, causing it to move back and forth from *a* to *b*. The admission of the steam to

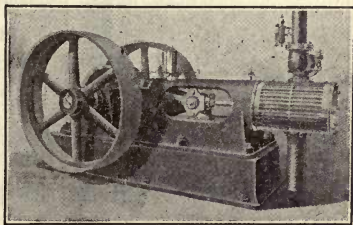


FIG. 204

the cylinder C is regulated by the sliding valve S , which admits live steam to one side of the cylinder and allows the exhaust or dead steam to escape on the other side. The motion of the valve S and that of the piston P are in opposite directions. (Supplement, 567.)

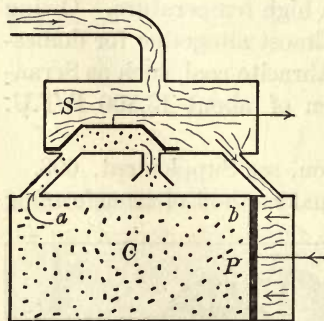
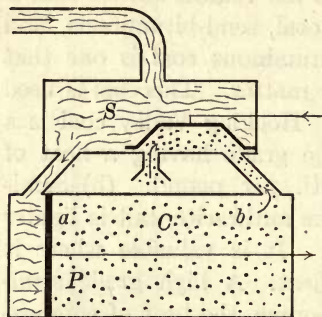


FIG. 205

263. The Gas Engine. In the gas engine an explosive mixture of air and gas or gasoline is admitted to the cylinder C , Fig. 206, and exploded by means of an electric spark. The explosion of the gas gives rise to a sudden expansion which causes the piston to move. The inertia of the flywheel carries the piston back to the upper end of the cylinder, where an explosion of the confined gas again takes place, these explosions being so timed as always to occur when the piston is in the position shown in the figure. The waste or exploded gas is discharged from the cylinder through the valve v' between explosions. (Supplement, 568.)

264. Efficiency. *The efficiency of any piece of heat apparatus, whether it be a steam engine, a furnace, or an*

ordinary gas burner under a kettle, is the ratio of the useful energy gotten out to the total heat energy put in; that is,

$$\text{efficiency} = \frac{\text{useful energy out}}{\text{heat energy in}}$$

The efficiency of the ordinary locomotive is about 3 to 4 per cent, which means that for every hundred per cent of energy

put into it in the form of coal we get in return only about 3 to 4 per cent in the form of useful work. Considering the losses in both engine and boiler, that is, "from coal bin to flywheel," the efficiency of the modern stationary engine is about 8 to 12 per cent.

Example. One cubic foot of gas is burned under a kettle containing a gallon (8 pounds) of water. The temperature of the water is changed from 68° to 110° F. Find the efficiency of the burner and kettle. *Solution:* 1 cubic foot of gas gives 600 B.T.U. of heat. To change 8 pounds of water from 68° to 110° F. requires $8 \times 42 = 336$ B.T.U. Efficiency = useful energy out / heat in = $336 / 600 = 56$ per cent.

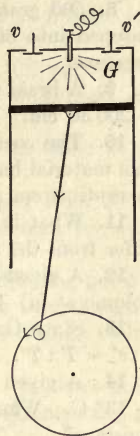


FIG. 206

EXERCISES. 18. A gallon of water (8 lbs.) is heated in a kettle on a gas range from room temperature (70° F.) to the boiling point (212° F.). How many B.T.U. go into the water?

19. If the efficiency of the burner and kettle (exercise 18) is 50 per cent, how many cubic feet of gas were consumed, assuming each cubic foot of gas to furnish 600 B.T.U.?

20. What is the cost of heating the water (exercise 18) at the rate at which gas is sold in your town?

EXERCISES AND PROBLEMS FOR REVIEW

1. Give the equivalent F. readings for the following: (a) 70° C.; (b) 50° C.; (c) 25° C.; (d) -5° C.; (e) -25° C.

2. Give the equivalent C. readings for the following: (a) 113° F.; (b) 77° F.; (c) 14° F.; (d) -13° F.

3. Find the boiling point and the freezing point of mercury (a) on the C. scale; (b) F. scale.

4. Find the boiling point and the freezing point of alcohol on (a) the C. scale; (b) F. scale.

5. The lowest temperature thus far obtained is said to be -271.3° C. What is this value on the Absolute scale?

6. How many calories of heat will be required to change the temperature of 100 grams of the following substances from 0° C. to 100° C.: (a) Water? (b) iron? (c) lead?

7. 100 grams of mercury at 100°C . are stirred with 100 grams of water at 20°C . and the resulting temperature is 22.6°C . Find the specific heat of the mercury.

8. 500 grams of copper, specific heat 0.09, temperature 120°C ., are dropped into 500 grams of water at 20°C . What is the resulting temperature?

9. A brass rod at 0°C . has a length of 200 cm.; at 100°C . its length is 200.36 cm. Find its coefficient of expansion.

10. The coefficient of expansion of nickel steel is 0.00001. A rod of this material having a length of 5 meters at 20°C . will have what length in centimeters at 12°C .?

11. What is the coefficient of expansion of gases, and wherein does it differ from the coefficient of expansion of solids?

12. A given mass of gas has a volume of 273 cc. at 0°C . Find its volume at (a) $+10^{\circ}\text{C}$.; (b) -10°C ., the pressure remaining constant.

13. State Gay-Lussac's law, and explain each term in the equation: $v : v' = T : T'$.

14. A given mass of gas free to expand has a volume of 500 cc. at -13°C . What will be its volume at $+27^{\circ}\text{C}$., the pressure remaining constant?

15. A liter of gas at -3°C . expands under constant pressure, due to a change of temperature, to 1200 cc. Find the change in temperature in Centigrade degrees.

16. State the laws of fusion, and illustrate their application to the melting of ice.

17. Define heat of fusion, and explain what is meant by saying that the heat of fusion of ice is 80 calories.

18. How many calories of heat will be required to change 10 grams of ice at zero to water at 20°C .?

19. How many calories of heat will be required to change 10 grams of ice at -10°C . to water at the boiling point, the specific heat of ice being 0.5?

20. State two ways by which the boiling point of water may be raised.

21. To what elevation in feet must water be taken above sea level in order that its boiling point be lowered to 90°C .?

22. State the laws of boiling, and explain their application to the boiling of water.

23. State and illustrate the laws of evaporation.

24. Define heat of vaporization, and explain what is meant by saying that the heat of vaporization of water is 538 calories.

25. How much heat is required to change 100 grams of ice at 0°C . to 100 grams of steam at 100°C .?

26. One kilogram of steam in a radiator at 100°C . condenses to water the temperature of which falls to 90°C . How many calories of heat are given out?

27. Give three methods of producing cold by artificial means, and give an example illustrating each.

28. Define and give illustrations of (a) conduction; (b) convection; (c) radiation. Explain wherein radiation differs from conduction and convection.

29. Define mechanical equivalent of heat, and give its value in (a) metric units; (b) English units.

30. The temperature of 10 grams of water is changed from 20°C . to the boiling point. Find (a) the number of calories of heat required; (b) the equivalent value in ergs.

31. One quart of water (2 lbs.) was heated from the freezing point to 132°F . (a) How many B.T.U. were required to effect this change of temperature? (b) The heat consumed by the water is equivalent to how many foot pounds?

32. One ton of hard coal of average grade is burned. (a) How many B.T.U. of heat are liberated? (b) How many cu. ft. of illuminating gas would be required to furnish the same quantity of heat?

33. Suppose that 10 tons of coal are required to heat a certain house for a year, the heating apparatus being a hot air furnace, the efficiency of which is 60 per cent. Find (a) the total number of B.T.U. liberated in the furnace; (b) the number of heat units delivered through the registers.

34. In one hour a 10 horse power engine burns 18 lbs. of coal. (a) How much work in foot pounds is done by the engine during the hour? (b) The burning of 18 lbs. of coal is equivalent to how many B.T.U.? (c) 18 lbs. of coal is equivalent to how much energy in foot pounds? (d) What is the efficiency of the engine?

35. Consult the table of heats of combustion, Supplement, 607, and determine the number of calories of heat liberated in the burning of 10 grams of (a) gun powder, (b) wood, (c) illuminating gas, (d) anthracite coal, (e) hydrogen.

For additional Exercises and Problems, see Supplement.

ELECTRICITY AND MAGNETISM

CHAPTER VII

MAGNETISM AND ELECTROSTATICS

MAGNETISM

265. The Natural Magnet. In many parts of the earth there is found a kind of iron ore called magnetite (Fe_3O_4) which possesses the properties of a magnet; that is, it attracts iron, Fig. 207, and when suspended points in a north-south direction, Fig. 208. A piece of this ore is called a natural magnet, or



FIG. 207

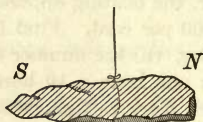


FIG. 208

lodestone. Any substance which is attracted or repelled by a natural magnet is called a *magnetic substance*. The name magnet is said to come from the fact that a magnetic substance was first found in Magnesia, Asia Minor, and that the term lodestone (leading stone) is probably due to the fact that it was used in early times by navigators as a sort of crude mariners' compass.

266. Properties of the Magnet. The fundamental property of the magnet may be demonstrated by the following experiments: (a) Bring one end of a bar magnet near some pieces of iron, such as small nails, tacks, or iron filings. It attracts the

iron. The filings leap to the poles of the magnet and cling tenaciously. (b) Roll the magnet in the iron filings; great tufts cling to the ends, Fig. 209. (c) Now suspend a light bar magnet (a magnetized knitting needle) so as to move freely about an axis, Fig. 210. It takes a north-south position, the end pointing toward the north being called the north-seeking pole; the end pointing to the south, the south-seeking pole.



FIG. 209



FIG. 210

The north-seeking pole is usually marked N or +; the south-seeking pole, S or -.

A *magnet* is a magnetic substance which has poles.

267. How to Magnetize a Body. Experiment. If a piece of steel, such as a bit of clock spring, a needle, or the blade of a pocket knife, be drawn several times in one direction across the end of a magnet, it will itself become a magnet. Consider, for example, the case of the knife. If the blade be drawn across the N-pole of the magnet from heel to point, the heel of the blade will be an N-pole and the point an S-pole, Fig. 211. If the blade be drawn in a similar manner across the S-pole of the magnet, the polarity of the blade will be reversed. The greater the number of times the steel is drawn across the magnet, the greater will be the pole strength, up to a certain point at which the steel is said to become magnetically saturated.

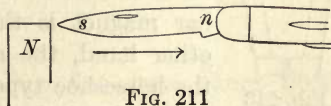


FIG. 211

268. Magnetic Substances. Experiment. If the pole of a magnet be brought successively in contact with pieces of iron, copper, brass, wood, and paper it will be found that the iron is strongly attracted, while the copper, brass, wood, and paper

are not noticeably affected. The iron is magnetic; the others are non-magnetic. A magnetic substance is one that is attracted or repelled by a magnet. Iron is highly magnetic; cobalt and nickel are also magnetic, but to a less degree than iron. Some magnetic substances, antimony (Sb) and bismuth (Bi) for instance, are slightly repelled by a magnet and are said to be diamagnetic.

269. Kinds of Magnets. Magnets may be classified in various ways, as for example: (a) natural and artificial magnets; (b) permanent and temporary magnets; and with reference to their form; (c) bar and horseshoe magnets, Fig. 212. All

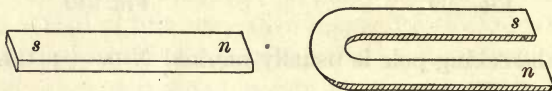


FIG. 212

manufactured magnets are artificial magnets. Permanent magnets are made of highly tempered steel and retain their magnetic properties for a long time; magnets made of soft iron soon lose their magnetic properties, and for this reason are called temporary magnets. Whether the magnet be of the bar or horseshoe form is determined by its use. When we desire to use a single pole, the bar magnet is the more convenient; when, on the other hand, the maximum lifting effect is desired, the horseshoe type is employed. Sometimes a short



FIG. 213

piece of soft iron, called an armature or keeper, is placed across the end of the magnet, Fig. 213. The use of the keeper is to prevent the magnet from losing its strength, as will be explained later.

270. Law of Attraction and Repulsion. *Experiment.* Present to the north-seeking pole of the magnetic needle the N-pole of a magnet, Fig. 214; the like poles repel. Now present to the north-seeking pole of the needle the S-pole of the magnet;

the unlike poles attract. From this experiment we may deduce the first law of magnets; namely, *like poles repel; unlike poles attract.*

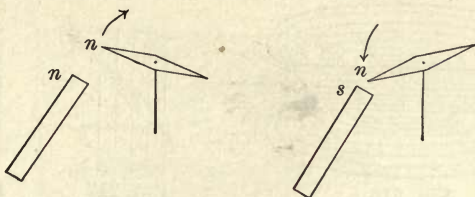


FIG. 214

271. Magnetic Field and Lines of Induction. The magnetic field is that portion of space surrounding a magnet which is affected by the magnet. *Experiment.* The magnetic field

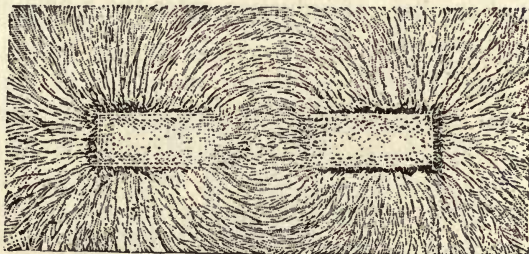


FIG. 215

may be mapped out by sprinkling fine iron filings upon a glass plate and placing the plate over a magnet. Tap the plate gently. The filings arrange themselves in curved lines, in response to the magnetic force acting upon them, Fig. 215. These lines were called by Faraday lines of force, but since the tendency in modern practice is to use the term lines of induction, we shall throughout this text speak of the lines in the magnet field as *lines of induction*. *These lines of induction are conceived of as coming out of the N-pole and passing in closed*

curves around to the S-pole, and thence through the magnet back to the N-pole, as shown in Fig. 216.

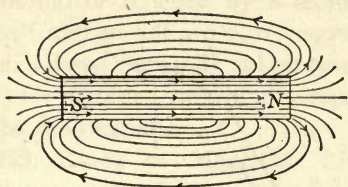


FIG. 216



FIG. 217

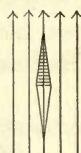


FIG. 218

272. Effect of the Field on a Magnetic Needle. The position which a magnetic needle assumes is determined by the direction of the lines of induction of the magnetic field. If a needle be placed in a magnetic field as shown in Fig. 217 it will tend to set itself in the direction of the magnetic force in such a manner that the lines of induction enter the S-pole and come out of the N-pole, Fig. 218.



FIG. 219

273. Magnetic Field for Like and Unlike Poles. (a) Fig. 219 shows the condition of the lines of induction in a magnetic field between like poles. The crowding together of the lines which emanate from the N-pole suggests an explanation for the fact that like poles repel. (b) The field between unlike poles is shown in Fig. 220. In this case the curved lines tend to contract, thus producing attraction.

274. Magnetic Induction. *Experiment.* We have seen that when a piece of iron is placed in contact with a magnet it too becomes magnetized. The iron may be magnetized, however,

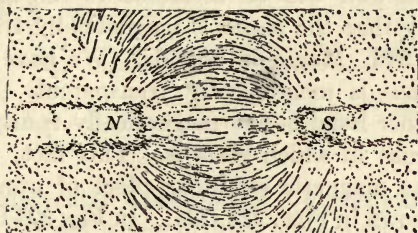


FIG. 220

without actually coming in contact with the magnet. Place one end of a soft iron nail in iron filings, then bring near to the other end the pole of a bar magnet. If now both nail and magnet be lifted it will be observed that tufts of iron filings cling to the lower end of the nail, Fig. 221, thus showing that it is magnetized even though not in actual contact with the permanent magnet. When the magnet is removed, then the nail at once loses its magnetism, the iron filings falling away. While the nail is influenced by the presence of the magnet, it is said to be magnetized by induction. If the pole of a magnet be brought near a piece of iron or other magnetic substance, there will be induced in the iron on the side next the magnet a pole of the opposite kind, and in the side farthest from the magnet a pole of the same kind.



FIG. 221

275. Magnetic Transparency. A great many substances such as glass, paper, wood, etc., seem to be transparent to magnetic induction. Such substances are said to be "magnetically transparent." *Experiment.* If iron filings be sprinkled on a glass plate and the plate be placed upon a magnet, the

filings will become strongly magnetized, thus showing that the glass is magnetically transparent. If we place between a magnetic pole and a piece of iron a sheet of paper, Fig. 222, the iron will be attracted to the magnet, showing that the paper is magnetically transparent.

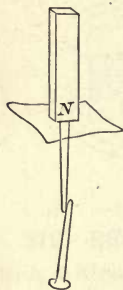


FIG. 222

276. Magnetic Shields. We have learned that glass is magnetically transparent. Iron on the other hand is not magnetically transparent in the sense in which glass is. This fact, together with the magnetic shielding effect of iron, is very well shown in Figs. 223, 224. In Fig. 223 there is shown the passage of the lines of induction through the sides of a glass vessel placed in a strong magnetic field. Fig. 224 illustrates the shielding effect of an iron ring, the lines of induction passing around through the iron from one pole to the other. An object, a watch for example, placed at *A* within the ring will be effectually shielded from the magnetizing force of the field.

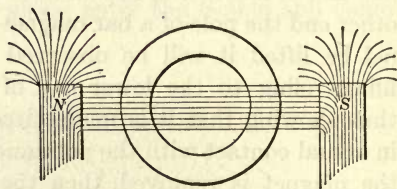


FIG. 223

277. The Effect of Break-

ing a Magnet. Experiment. Suppose that we magnetize a thin strip of steel (a piece of clock spring). It has a pole at each end and a neutral point in the middle. Now if this magnet be broken at the middle it will be found that each piece is a magnet, Fig. 225. If each piece be again broken the smaller

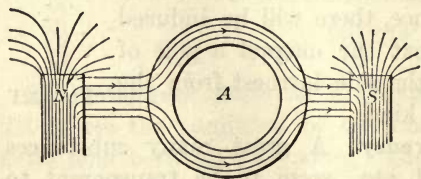


FIG. 224

pieces will still be magnets. Thus we may conceive the breaking process to go on until the molecule is reached. The con-

clusion from this and other experiments is that a magnet possesses its magnetic properties because of the fact that its molecules are magnets.

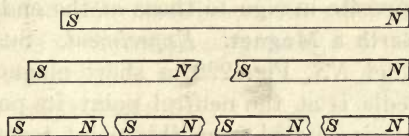


FIG. 225

278. The Molecular Condition of Unmagnetized and Magnetized Iron. When a bar of iron is unmagnetized its molecules are supposed to point in every conceivable direction, as shown in Fig. 226. When it is magnetized the molecules point in a definite direction, Fig. 227, thus giving the bar polarity.

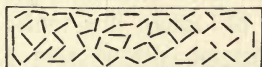


FIG. 226

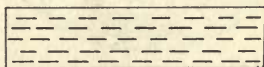


FIG. 227

If a bar magnet be dropped or jarred violently, it is said to lose its magnetism. What really happens is that the molecules rearrange themselves again, taking up the position as in Fig. 226. Strictly speaking, the bar has as much magnetism as before; what it has lost is its polarity.

279. Consequent Poles. *Experiment.* Every magnet has two poles. A bar may be magnetized, however, so that it will have within itself a number of magnets, and hence a number

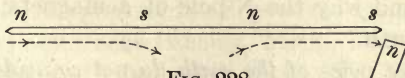


FIG. 228

of poles. The poles which occur in a magnet other than at the ends are called *consequent poles*. If the poles of a permanent magnet be drawn along a piece of steel (knitting needle), skipping at several points, Fig. 228, the needle will contain

two or more consequent poles. It is possible to magnetize a steel bar in such a way that both ends may be either N-poles or S-poles. The bar will of course in this case contain consequent poles opposite in sign to those at the end.

280. The Earth a Magnet. *Experiment.* Suspend above a long bar magnet *NS*, Fig. 229, a short magnetic needle *ns*. When the needle is at the neutral point, its position is horizontal; when it is carried from this point toward either pole,

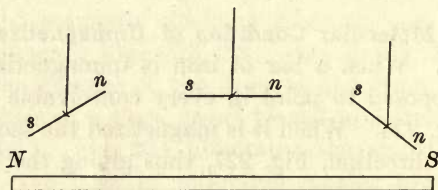


FIG. 229

it dips more and more, until the pole is reached, when its position is vertical. Now if a magnetic or dipping needle be carried on the surface of the earth from the equator toward the poles, it will be observed to dip in a similar manner. This means that the earth behaves exactly as if it were a magnet, having one magnetic pole near the north geographic pole and the other near the south geographic pole. The earth's magnetic pole at the north corresponds to the S-pole of a bar magnet; the magnetic pole at the south corresponds to the N-pole of a bar magnet. Since unlike poles attract, we thus understand why the N-pole of a magnetic needle points toward the north.

The magnetic poles of the earth do not coincide with the geographic poles, the magnetic pole of the north, for example, being more than 1000 miles from the geographic pole. The magnetic pole of the north is in the northern part of British America, about 70° N. latitude and longitude 97° W., Fig. 230.

281. The Angle of Declination. We sometimes say that the magnetic needle points north-south. This, however, is very rarely true. *True north from any point on the earth is the direction from that point to the north geographic pole.* Now the magnetic needle points to the magnetic pole, and as we have already learned, these two poles do not coincide. The angle made by the needle and true north is called the *angle of declination*.

Experiment. To find the angle of declination for a given place one may proceed as follows: Drive two stakes into the ground in such a position that a string stretched from one to the other will point to the North star, which determines very closely the direction of the north geographic pole.

The string therefore lies on a geographic meridian; that is, it points true north-south. Now place a long magnetic needle just below the string. The angle made by the needle and the string is the angle of declination. The declination for Ann Arbor, Mich., is at present very nearly two degrees, the needle pointing west of true north.

In some places the needle points to true north. A line drawn through such places is called a *line of no declination*, or an *agonic line*. At present the line of no declination for the United States passes near Lansing, Mich., Fort Wayne, Ind., Cincinnati, Ohio, and Charleston, S. C. For all points east of this line the declination is toward the west; for points west of it, the declination is toward the east.

282. Variation in the Direction of the Magnetic Needle. The magnetic poles are not fixed in position. The north magnetic pole, for example, swings slowly back and forth in an

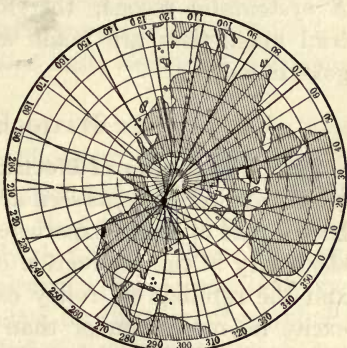


FIG. 230. Magnetic Pole of Northern Hemisphere

east-west direction, requiring several centuries to make a complete vibration. This shifting of the magnetic poles, together with other causes not very well understood, gives rise to a continual variation in the angle of declination. In surveying land it is very important that this variation shall be known. A systematic record, therefore, of all variations of terrestrial magnetism are made and kept by the United States government.

STATIC ELECTRICITY

283. The Nature of Electricity. Phenomena connected with electrical discharges, as seen in the flash of lightning, have always been a part of man's experience, and in modern times the use of electricity in the production of light, the ringing of door bells, and the running of trolley cars has become so familiar as to excite no more wonder than the phenomena associated with gravitation, heat, or sound. There is, however, one very important difference between these two sets of phenomena. In the case of heat, for example, we know not only what it does but what it is; in the case of electricity, on the other hand, we know what it does, but we do not know what it is. We know that the energy of a current of electricity may be transformed into heat, light, or mechanical motion, but what electricity itself is no one at present knows.

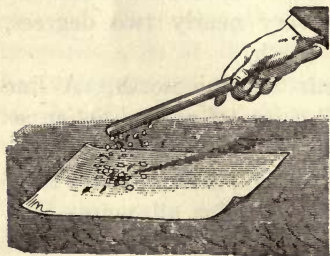


FIG. 231

284. Electrification. Experiment. Since the days of the ancient Greeks it has been known that when certain bodies were rubbed together they possessed the power of attracting other bodies. For example, if a glass rod be rubbed with silk it will

attract a light pith ball or bits of paper, Fig. 231. We say that the glass rod is electrified. In a like manner we may

electrify a stick of sealing wax by rubbing it with flannel or cat's fur. Other familiar illustrations are seen in the electrification of a rubber comb when drawn through the hair, or in the electric discharge which occurs when the hand is drawn over a cat's back on a dry day.

A study of the phenomena of electrification is usually considered under that division of electricity known as static electricity. *Electricity in a state of rest is called static electricity; electricity in motion, current electricity.*

285. Two Kinds of Electrification. It was early discovered that there are two kinds of electrification, one called positive (+), the other negative (-). A glass rod rubbed with silk is said to be positively electrified; a stick of sealing wax rubbed with flannel or cat's fur, negatively electrified. There are many other substances which may be electrified, some positively and some negatively. We shall, however, for the sake of simplicity and clearness, think of glass rubbed with silk as a type of positively electrified bodies, and sealing wax rubbed with flannel as a type of negatively electrified bodies. We shall also speak of electrified bodies as being charged positively or negatively, as the case may be.

There is no very good reason for calling the electrical charge on glass positive (+) and that on sealing wax negative (-), other than the fact that these terms were adopted when the subject was first studied. (Supplement, 597.)

286. Attraction and Repulsion. Among the most familiar phenomena of electrification are those of attraction and repulsion. If a rod be electrified and brought near a light body, such as a pith ball, two things may be observed: (a) The pith ball is at first attracted to the electrified rod, Fig. 232, and (b) after a moment in contact, it is repelled.

It is important to note that whenever an electrified body is brought near another body, attraction or repulsion always results.

287. Laws of Attraction and Repulsion. Experiment. Charge a glass rod positively and suspend it in a stirrup, as

shown in Fig. 233. Bring near the suspended rod another glass rod also positively charged. The two repel each other.

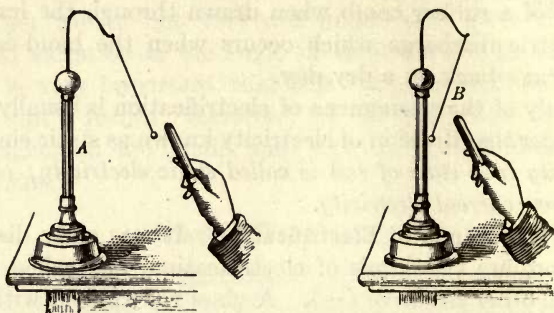


FIG. 232

Now present to the suspended glass rod a stick of sealing wax which has been negatively charged. The two attract each other.

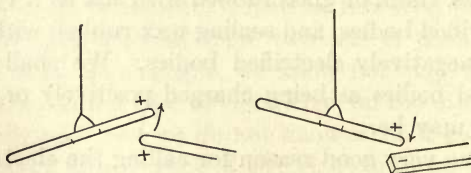


FIG. 233

Law of signs: *Charges of like sign repel; charges of unlike sign attract.*

288. Discussion of Attraction and Repulsion. We are now prepared to explain, in a measure, the phenomena of attraction and repulsion. If a glass rod positively charged be brought near a pith ball, Fig. 234, there will be induced on the side of the pith ball nearest the rod a $-$ charge, and on the side farthest from the rod a $+$ charge. The positive charge on the ball is exactly equal in quantity to the negative charge. Now since unlike signs attract and like signs repel, it follows that the $-$ charge will tend to move toward the glass rod and the $+$ charge away.

The force of attraction, however, is greater than the force of repulsion, since the $-$ charge on the ball is nearer to the rod than is the $+$ charge. The moment the two come in contact, the negative charge on the ball is neutralized by some of the positive charge on the rod, and there remains on both rod and ball positive charges. Since charges having like signs repel each other, the ball is now driven away from the rod.

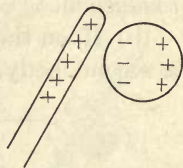


FIG. 234

The above explanation of attraction and repulsion will apply whether the charging body has either a negative or a positive charge upon it.

289. The Two Kinds of Electrification Equal in Quantity. Experiments seem to prove that whenever a body is charged with electrification of one kind there is somewhere developed an equal charge of the opposite sign. Thus when a glass rod is rubbed with silk, a positive charge is developed upon the rod and an equal negative charge is developed upon the silk; similarly when sealing wax is rubbed with flannel, a negative charge occurs on the sealing wax and an equal positive charge upon the flannel.

To prove that positive and negative charges are always developed in equal amounts, Faraday used an ebonite rod upon which was fitted a flannel cap, Fig. 235. He electrified the two bodies by twisting the rod inside the cap and then removed the latter by means of a silk string attached to it. He tested both the charge upon the rod and that upon the cap and found that not only was the charge on the rod positive and that on the cap negative, but also that the two were exactly equal in quantity.



FIG. 235

290. Charging by Conduction and Induction. A body may be charged electrically in two ways: by conduction and by induction.

(a) If a charged body be brought in contact with another

body, some of the electricity on the first will flow off upon the second body. Thus the second body is said to be charged by *conduction*.

(b) If, on the other hand, the charged body be brought near a second body, there will occur upon the latter two charges

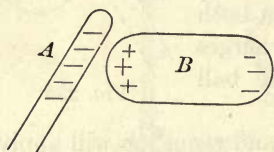


FIG. 236

equal in quantity and opposite in sign, Fig. 236. In this case the + charge is said to be *bound*; the - charge is *free*, and tends to get as far as possible from the - charge on the rod. If a finger be touched

to the charged body B, the free - charge will flow off. If now the charging rod A be removed, there will remain on B the + charge. B is then said to be charged by *induction*.

291. The Electroscope. An *electroscope* is an instrument for detecting the presence of charges of static electricity. It consists of two leaves of gold foil attached to a metal rod, Fig. 237, the whole being enclosed in a glass flask. The ob-



FIG. 237

ject of the flask is to protect the leaves of the electroscope from drafts of air or injuries from contact.

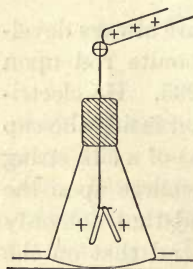


FIG. 238

292. How to Charge the Electroscope by Conduction. *Experiment.* If a charged body be brought in contact with the electroscope, Fig. 238, some of the electricity will flow off the body onto the electroscope, distributing itself over the knob and leaves. The leaves of the instrument, being charged with electricity of like signs, will repel each other.

When the charging body is removed it will have lost a quantity of electricity equal to that gained by the electroscope. When an electroscope is charged by conduction the charge upon it is similar in sign to that on the charging body.

Sometimes it is desired to convey a definite portion of a charge to the electroscope. This may be done by means of a *proof plane*, which consists of a small metal disc attached to a nonconducting handle, Fig. 239, and which is used to transfer small charges from one body to another. For example, if a proof plane be touched to a charged body, such as the pole of an electric machine, and then conveyed to the knob of the electroscope, a slight divergence of the leaves will result. Upon conveying a second charge a further divergence will occur. In this way it is possible to convey as much electricity to the electroscope as is desired.



FIG. 239

293. How to Charge an Electroscope by Induction. *Experiment.* Bring a charged body (positively charged, say) near the knob of the electroscope. There will be induced upon the knob a negative charge and upon the leaves an equal positive charge. The negative charge is bound, and the positive charge free. Now if a finger be touched to the electroscope, the free positive charge, being repelled by the charge on the glass rod, will flow off to the earth. Remove the finger, and afterward remove the charging body. There will then remain upon the electroscope a negative charge which will distribute itself over the metallic part of the instrument. The electroscope is now charged by induction, Fig. 240. *It will be noted that when the*

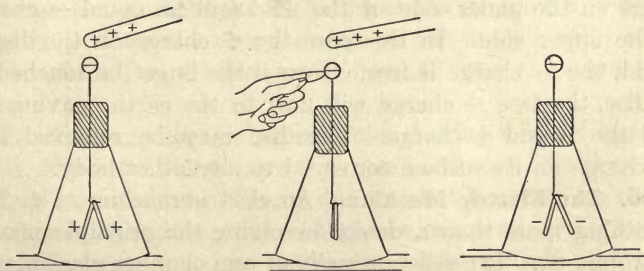


FIG. 240

electroscope is charged in this manner, that is, by induction, the charge upon it is of the opposite sign to that on the charging body.

294. The Electrophorus. It is sometimes desirable to charge a body with a larger quantity than can be obtained upon a glass rod or a stick of sealing wax. To do this an *electrophorus* may be employed, Fig. 241. This consists of a shallow dish containing resin, sealing wax, vulcanite, or some similar nonconducting material. A metal disc of a size suitable to fit the dish is provided with an insulating handle.

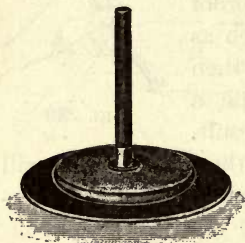


FIG. 241
Electrophorus

To charge the electrophorus apparatus, we rub the nonconducting material with flannel or cat's fur, thus giving it a — charge, Fig. 242. If now we place the metal disc upon the surface of the apparatus, only a very small quantity of electricity will flow to the metal, because of the nonconducting property of the resin or other substance used. The — charge on the resin induces a +

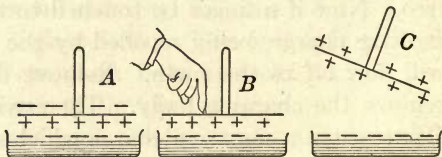


FIG. 242

charge on the under side of the disc and an equal — charge on the upper side. In this case the + charge on the disc is bound, the — charge is free. Now if the finger be touched to the disc, the free — charge will flow to the earth, leaving behind the bound + charge. The disc may be removed and the charge on its surface conveyed to any other body.

295. The Electric Machine. An electric machine, Fig. 243, is nothing more than a device involving the principle of the electrophorus. It consists usually of one or more glass plates, which on being rotated become charged, mainly by induction.

A cross metal bar serves to draw off the free electricity from the rotating disc, and the bound charge is then transferred to the discharging points.

For description of Toepler-Holtz and Wimshurst electric machines, see Supplement, 569 and 570.

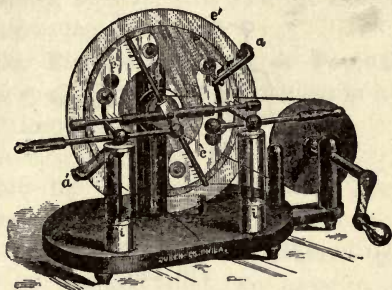


FIG. 243

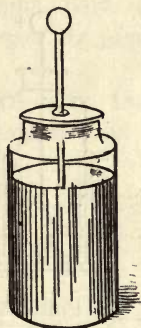


FIG. 244

296. The Leyden Jar. The *Leyden jar* consists of a glass vessel coated about two-thirds the way up on both the inside and the outside with tin foil, Fig. 244. A metal conductor communicates with the inner coating of the vessel. To charge the jar we grasp the outer coating in the hand and place the knob in contact with one of the poles of an electric machine, thus charging the inner coating by conduction. The outer coating becomes charged through the glass by induction. Suppose, for example, that the inner coating of the jar have a $+$ charge, Fig. 245. Then the bound charge on the outside will be negative and the free $+$ charge will flow off from the hand to the earth.

To discharge the jar a conductor having a glass handle is used, Fig. 246. Sometimes it is possible to obtain two or more sparks from the jar. This is due to what is called the residual charges. The glass when charged is supposed to be under a state of strain and does not entirely relieve itself on the first discharge.

The Leyden jar acts as a condenser. *An electrical condenser is a device for increasing the charge on a conductor without increasing the potential* (Art. 298). It consists of two or more sheets of tin foil separated by glass, paraffin paper, or other



FIG. 245

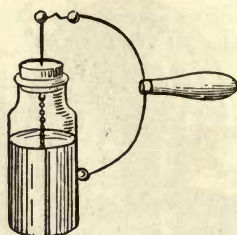


FIG. 246

nonconducting medium, called a dielectric. Condensers are very largely used in induction coils (Art. 398), and in many other kinds of modern electrical apparatus such as the telephone and wireless telegraph.

297. The Charge on the Glass. By means of a dissected Leyden jar, Fig. 247, it is possible to prove that the charge

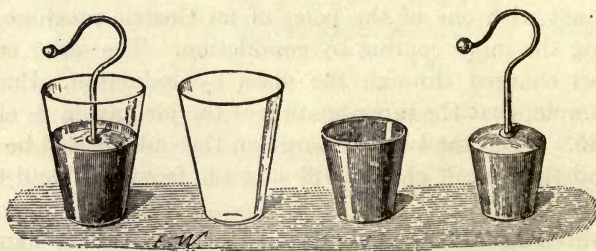


FIG. 247

resides on the glass and not upon the metal conductor (tin foil). Let the jar be charged. Then by means of a glass rod lift the inner coating out and remove the glass jar. Now bring the

two metal coatings together. No spark is produced, showing that there is no charge upon them. Now put the parts of the jar together again, using the glass rod to handle the inner coating as before, and connect the outer coating with the knob by means of the discharging apparatus. A bright spark will be obtained, *thus showing that the charge was upon the glass and not upon the metal.*

298. Electric Pressure or Potential. We have thus far been speaking of charged bodies in a very general way. It is now important that we get a little clearer notion of what is meant by the terms positive charge and negative charge, and also their relation to each other. Let us suppose that we have four tanks partly filled with water, Fig. 248, two above the surface of the earth and two below. The water in each tank exerts a pressure. The pressure in *A* is greater than that in *B*; the pressure in *C* greater than that in *D*. *Now this pressure exerted by the water is somewhat analogous to the electrical pressure exerted by a charged body.* Tanks *A* and *B* may be considered as analogous to positively charged bodies; tanks *C* and *D* to negatively charged bodies. And just as we consider the line *MN* as the zero line for the water pressure in the tank, so too for electricity we consider the earth as being of zero electric pressure or potential.

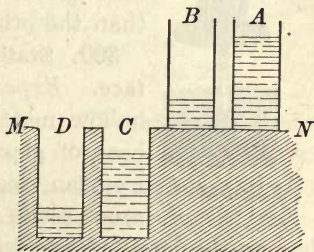


FIG. 248

Bodies charged positively have a potential higher than that of the earth; bodies charged negatively have a potential lower than that of the earth.

299. The Electric Current. If two bodies of *different potential* (electrical pressure) be connected by means of a wire or other conductor, a portion of the charge on the body of high potential will be conveyed along the conductor to the body of

low potential. This transfer of electricity from one body to another gives rise to what is called an *electric current*. Just as water may flow, in the case of the four tanks of Fig. 248, from *A* to *B*, or from *C* to *D*, or from either *A* or *B* to *C* or *D*, a current of electricity, in an analogous manner, may flow between (a) two positively charged bodies, (b) two negatively charged bodies, (c) or between positively and negatively charged bodies, provided always that one of the bodies is at a higher potential than the other.



FIG. 249

300. Static Charges Reside upon the Surface. *Experiment.* Place a tin cup or other hollow metallic vessel upon a nonconducting base of glass or paraffin and charge the cup from an electric machine, Fig. 249. Touch a proof plane to the outside of the vessel and then to the knob of an electroscope; the leaves are affected, showing that there is a charge on the outside of the vessel. Now, touch the proof plane to the inside of the vessel and again to the knob of the electroscope; the leaves are not affected, showing that there is no charge on the inside. A static charge resides on the outside of a conductor. To prove that even for very high potentials the charge remains upon the surface, Faraday used a cage made of metal rods, inside of which he placed a sensitive electroscope. He then charged the cage so heavily that a spark discharge occurred from different points on the surface; the electroscope, however, was not affected in the slightest degree.

It has been found by many such experiments that *a charge of electricity at rest, that is, static electricity, always resides upon the surface of the conductor.*

301. Distribution of the Charge. The distribution of the charge of static electricity upon the surface of a conductor depends upon two factors: (a) the shape of the conductor, (b)

the presence or absence of other charged bodies. *In the case of a spherical conductor free from the influences of other bodies, the charge is distributed uniformly over the surface, Fig. 250.* In case there are present other charged bodies the charge is distributed somewhat as shown in Fig. 251. *In the case of an irregular shaped body, the charge has its greatest density at the pointed portion of the conductor, Fig. 252.*



FIG. 250

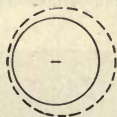


FIG. 251



FIG. 252

302. The Influence of Sharp Points. The effect of sharp points in connection with conductors is of great importance in the operation of certain types of electrical apparatus, and also in the application of the lightning rod in the protection of buildings. A sharp point serves to discharge the electricity upon a body, as may be shown by the following experiment. If an electroscope be charged the leaves will remain apart for some considerable time, depending upon the condition of the atmosphere and the nature of the instrument. (Supplement, 571.) If now the head of a pin or other sharp pointed body fastened to the end of a glass rod be brought in contact with the knob of the electroscope, the leaves will collapse very quickly, thus showing the effect of the discharging point.

303. Lightning. Benjamin Franklin was one of the first to demonstrate the similarity between that discharge of atmospheric electricity known as lightning and the discharge from a Leyden jar or an electric machine. During a thunderstorm he sent up a kite having a pointed wire at the top. The kite was provided with a hempen string, to the lower end of which was attached a key, Fig. 253. In order to control the kite and at the same time to prevent the charge from passing through his body, Franklin fastened to the kite string a piece of nonconduct-

ing silk ribbon, the end of which he held in his hand. When the hempen string became wet he succeeded in drawing from the key electric sparks which he concluded were similar in every respect to those that came from the Leyden jar.

Clouds become charged in a manner which may be somewhat analogous to that of the charge on the plates of an electric machine. When two clouds oppositely charged come near to each other the potential (electric pressure) may become so



FIG. 253. — Franklin's Kite Experiment

great that discharge takes place, resulting in a flash of lightning. The discharge from one cloud to another or from a cloud to the earth is similar in every respect to the discharge between the knobs of an electric machine, except that in the case of the atmospheric discharge the phenomenon occurs on a very much grander scale.

Observers sometimes imagine that they can see the flash of lightning go from one cloud to another. This is, however, an optical illusion, since the discharge, as in the case of an elec-

tric machine or Leyden jar, is oscillatory; that is, the discharge occurs back and forth a great many times in a second. The thunder which is associated with lightning is caused by the expansion of air created by the flash. Accompanying a lightning flash there is a sudden increase in volume of the air along the path of discharge, giving rise to violent vibrations of the atmosphere and causing the crashing or rumbling noise called thunder. Thunder, therefore, always follows the lightning flash and never precedes it.

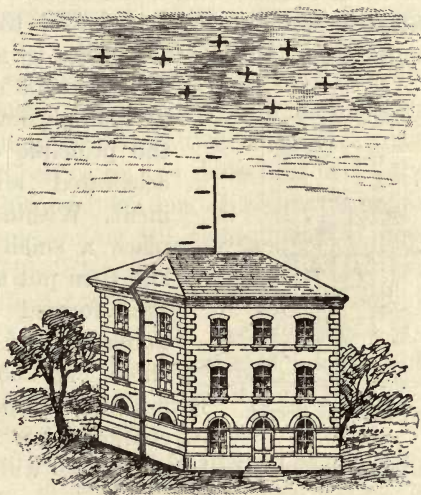


FIG. 254. — The Lightning Rod

304. The Lightning Rod. The lightning rod consists of a metal conductor provided with one or more sharp points, and having the lower end connected with the earth, Fig. 254. The exact importance of the lightning rod as a protection for buildings has not, up to the present time, been thoroughly determined. It is believed, however, that its principal functions are to furnish (a) a means of silent discharge between the earth

and the electrified atmosphere above, as illustrated by the principle of discharging points, and (b) to furnish a conductor to the earth in case the building is struck. It is now known that a lightning rod need not be made of any particular sort of metal or that it be of any special shape; heavy iron wire serves the purpose very well. The important facts to be kept in mind in installing lightning rods are (a) that the wires are to be so put up as to furnish a number of discharging points at the top of the building, and (b) that the lower end be buried deep enough so as to be in contact with moist earth.

305. The Electric Screen. It is believed that the most effective protection from lightning is furnished by metal screens.

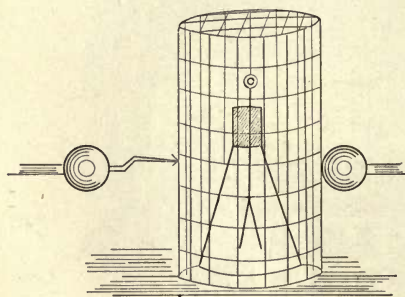


FIG. 255. — Electric Screen

This may be demonstrated by a simple device involving the principle of Faraday's celebrated screen experiment. Within a wire screen place a small electroscope and then put the apparatus thus formed between the knobs of an electric machine, Fig. 255. When the machine is operated a discharge takes place across

the screen, during which the electroscope will remain undisturbed.

Warehouses and other buildings containing highly inflammable material are sometimes protected in this way by having stretched over them a network of metal conductors which are thoroughly grounded at a number of points. The screen effects of the metal roofs, girders, gas and water pipes which cover the modern structures of our cities probably explain why such buildings are so rarely injured by lightning.

CHAPTER VIII

CURRENT ELECTRICITY

THE ELECTRIC CELL

306. The Simple Voltaic Cell. *Experiment.* Into a dilute solution of sulphuric acid place a strip of copper and a strip of zinc, so that they are a few centimeters apart. If the copper and the zinc be now connected by means of a wire, as shown in Fig. 256, a current of electricity will flow through the wire, as may be demonstrated by the ringing of an electric bell or by the deflection of a galvanometer. This combination of copper, zinc, and acid is a simple voltaic cell, thus named in honor of Volta (1748–1827), an Italian physicist, who was one of the first to experiment with and describe such a device. *The essential parts of a simple voltaic cell are two metals and a solution, the metals to be of such a nature that the solution acts upon one of them more readily than upon the other.*

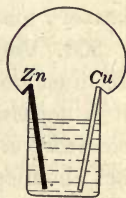


FIG. 256

A *voltaic cell*, then, may be defined as a device for transforming the energy of chemical action into the electrical energy of a current.

307. Terms Used in Connection with the Electric Cell. The solution used in a voltaic cell is called the *electrolyte*. The two metals are the *electrodes*. That portion of an electrode which is immersed in the solution is sometimes called the *plate*, and the portion to which the wire is attached, the *pole*. The electrode which becomes positively charged is the *positive electrode*; the one negatively charged the *negative electrode*. The electrode which is least affected chemically is usually the positive elec-

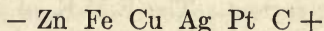
trode; the one most affected chemically the negative electrode. For example, in the case of the cell described in the preceding topic, the copper is the positive electrode, the zinc the negative. The direction of the current through the wire is assumed to be from the copper to the zinc; that is, from the positive to the negative electrode. The entire path of the current is called the *circuit*. That part outside the liquid is the *external circuit*; the part within the liquid, the *internal circuit*. Any part of the circuit, as the wire connecting the electrodes, is called a conductor. Metals in general are good conductors. Substances like glass and rubber are poor conductors. A poor conductor of electricity is called an insulator.

A number of cells joined together constitute a *battery*. A battery may consist of a single cell or a number of cells.

308. Voltaic Cells with Different Electrolytes. *Experiment.* It must not be supposed that in order to make a voltaic cell it is necessary to use a dilute solution of sulphuric acid as the electrolyte. Any solution, be it acid, base, or salt, which will act chemically upon the one electrode more readily than upon the other, will serve as an electrolyte. This may be shown by the following experiment. Use electrodes of copper and zinc, connecting the poles to a galvanometer. Dip these electrodes successively into the following solutions, rinsing the electrodes in water after each test: (a) Dilute sulphuric acid; (b) dilute hydrochloric acid; (c) dilute acetic acid (vinegar); (d) solution of sodium chloride (NaCl). In each case the galvanometer is deflected, showing that a current is set up by the cell. If the electrodes be thrust, for example, into an apple, Fig. 257, a current will also flow, due to the action of the juices of the apple upon the metals. In fact almost any vegetable will act chemically upon the zinc sufficiently to set up a current.

309. Voltaic Cells with Different Electrodes. *Experiment.* In this experiment it is desired to show that different substances may be used as electrodes. Take as the electrolyte a dilute solution of sulphuric acid. First, use as electrodes copper and

zinc. The copper, as we have seen, is positive to the zinc, causing the pointer of the galvanometer to be deflected in a given direction. •Second, use as electrodes copper and carbon. The current now flows through the galvanometer in the opposite direction; that is, from the carbon to the copper, as shown by the opposite deflection of the pointer. The copper is in this case the negative electrode. By similar experiments it may be shown that copper is positive to zinc and iron, but is negative to silver, platinum, and also, as has been shown, to carbon. In the following list any element, copper for example, is positive to the elements on the left of it and negative to elements on the right:



Thus iron is positive to zinc and negative to copper, while copper is positive to iron, but negative to silver. The farther any two elements in the list are removed from each other, the greater is the terminal potential difference of the cell. In most commercial cells zinc and carbon are used as electrodes.

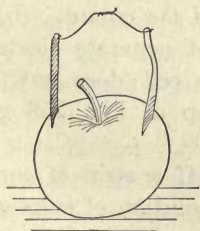


FIG. 257

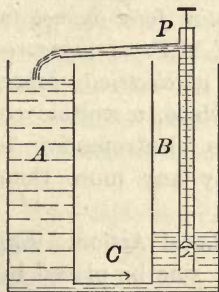


FIG. 258

310. Potential Difference and Electromotive Force. The student is already familiar with the idea that currents of electricity flow from points of high potential to those of low potential in a manner analogous to the flow of water from a point of high pressure to one of low pressure, Fig. 258. Let

us suppose that the water flows from one tank to the other through the pipe *C*, and that the difference of level in the two tanks is maintained by the operation of the pump *P*. We may consider such a system as somewhat analogous to that of an electric cell, the difference in pressure between *A* and *B* corresponding to the difference of potential between the electrodes of the cell. In the case of the water the difference of level is maintained by the expenditure of energy through the agency of the pump; in the electric cell the difference of potential is maintained by the expenditure of energy due to chemical action.

The electromotive force (E.M.F.) of a voltaic cell is that which tends to produce a current. The E.M.F. of a cell is equal to the difference of potential between the electrodes when the circuit is open; it is equal to the fall of potential around the entire circuit when the circuit is closed.

In connection with the electromotive force it is important to note two things: (a) While we speak of electric pressure as being *analogous* to water pressure, it must be borne in mind that *electromotive force is not force*, nor is it measured in units of force; E.M.F. is measured in units of work (ergs) per unit quantity of electricity conveyed around the circuit. (b) In the second place, a voltaic cell does not generate electricity; it generates electromotive force. The cell does not generate electricity any more than the pump of Fig. 258 generates water.

311. Local Action. *Experiment.* If a strip of commercial zinc be placed in a dilute solution of sulphuric acid, chemical action at once takes place. The zinc is dissolved, forming zinc sulphate and liberating hydrogen. The reaction may be written $\text{Zn} + \text{H}_2\text{SO}_4 = \text{ZnSO}_4 + 2\text{H}$. *This chemical action is called local action. It is due to impurities in the zinc in the form of tiny particles of carbon, iron, etc. Each*



FIG. 259

particle constitutes, with the zinc and acid, a voltaic cell,

Fig. 259. If the zinc were perfectly pure there would be no local action. *Local action is detrimental* because it represents a useless waste of zinc, giving rise to chemical action, but furnishing no useful current to the circuit. It *may be prevented* by coating the zinc plate with mercury; that is, amalgamating the zinc.

312. Effect of Amalgamating the Zinc Plate. Experiment. To demonstrate the effect of amalgamating the zinc plate, take a strip of commercial zinc and after cleaning it by immersing it for a few moments in dilute sulphuric acid, rub mercury over its surface until the latter becomes bright and mirror like. The impurities in the zinc are then covered by the mercury, which not only spreads over to every part of the plate, but also penetrates to a considerable depth. If the amalgamated plate thus formed be now placed in the acid, no chemical action will occur, so long as the zinc is not a part of the electrical circuit of the cell. If, however, the amalgamated zinc plate be connected to the copper electrode by means of a wire, chemical action will at once take place between the acid and the amalgamated zinc, all the energy being now used to furnish a current. Thus it appears that amalgamating the zinc plate prevents local action, but at the same time does not hinder in any way the zinc from acting as the negative electrode when connected with the positive electrode by means of an external circuit.

313. Polarization. Experiment. If we close the circuit of a simple voltaic cell consisting of dilute sulphuric acid and electrodes of copper and amalgamated zinc, bubbles of hydrogen will appear in large numbers on the copper electrode, Fig. 260. This appearance of hydrogen on the positive electrode does not mean that the copper is being dissolved by the acid; it does mean, however, that the hydrogen from the electrolyte

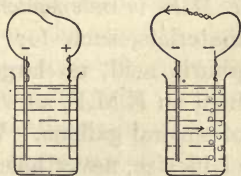
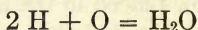


FIG. 260

is transferred during the operation of the cell from the solution to the positive electrode, upon which it forms a gaseous layer. This collection of H on the positive electrode reduces the E.M.F. of the cell (Supplement, 572), thereby cutting down the current. When in this condition the cell is said to be polarized.

Polarization is the reduction of the E.M.F. of a cell due usually to the collection of hydrogen on the positive electrode.

314. Polarization, How Remedied. *Polarization is detrimental* because it reduces the E.M.F. of the cell. *It may be remedied* by adding to the electrolyte an oxidizing agent; that is, a substance which will furnish oxygen to unite chemically with the hydrogen on the electrode and thus form water, as represented by the chemical equation



One of the most desirable oxidizing agents for depolarizing purposes is a solution of chromic acid. Next in importance is a solution of sodium bichromate. Potassium bichromate is sometimes used; it is not so satisfactory, however, as the sodium bichromate on account of the insoluble crystals which it forms.

315. Factors that Determine the E.M.F. of a Cell. The electromotive force of a cell is determined by three factors: (a) the kind of electrodes used, (b) the nature of the electrolyte, and (c) the temperature at which the cell operates. *The E.M.F. is independent of the size of the plates.* A cell of given materials, such for example as zinc, copper, and dilute sulphuric acid, no larger than a lady's thimble will furnish as high an E.M.F. as will a similar cell having a volume capacity of several gallons. While the E.M.F. of a cell is independent of its size, nevertheless a large cell is, in general, more desirable than a small one, because the larger the cell the less the resistance, and hence the greater the current, and also the larger the cell the longer will its material last to furnish a current.

KINDS OF CELLS

316. Classification of Cells. There are many different types of cells, depending on (a) their form, (b) the character of the electrodes, and (c) the nature of the electrolyte. In this text only a few of the more common types will be considered; namely, the gravity cell, the Leclanche cell, and the dry cell.

317. The Gravity Cell. A form of the *gravity cell* is shown in Fig. 261. The positive electrode consists of a piece of copper, Cu, placed at the bottom of the cell. The negative electrode is a piece of zinc, Zn, of the crowfoot form, suspended from the upper margin of the battery jar. The wire leading from the copper electrode to the pole must be well insulated.

The cell is set up as follows: Crystals of copper sulphate are placed in the bottom of the battery jar, which is then filled with water. A few drops of sulphuric acid are added to the water in contact with the zinc. This acid reacts upon the zinc, forming a dilute solution of zinc sulphate, which being lighter than copper sulphate remains near the surface. We thus have in the battery two different solutions; namely, a saturated solution of copper sulphate in contact with the copper plate, and a dilute solution of zinc sulphate in contact with the zinc plate. Batteries of this type are called two-fluid batteries. When the cell is in action zinc dissolves from the negative plate and goes into solution; copper from the electrolyte goes out of solution and is deposited upon the copper plate. Thus the zinc plate grows lighter as the cell continues in use, and the copper plate grows heavier. Since there is no hydrogen involved in the operation, no polarization occurs. *Herein lies the great advantage of cells of this type; namely, the cells do not polarize.* The gravity cell is used where continuous

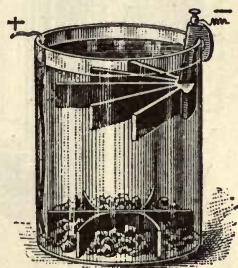


FIG. 261.—Gravity Cell

currents are desired, as, for example, in the *closed circuit work* of telegraphy. (Supplement, 573.)

The *Daniell cell* is another type of the two-fluid battery, differing from the gravity cell only in form, Fig. 262. The copper sulphate is placed in the outer chamber of the cell; the zinc plate and zinc sulphate solution, in the inner chamber, which consists of a porous cup.

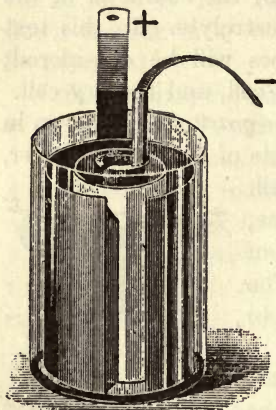


FIG. 262
Daniell Cell

The E.M.F. of both the gravity and the Daniell cell is about 1 volt.

318. The Leclanche Cell. This cell consists of a vessel, as shown in Fig. 263, which contains a solution of ammonium chloride. A rod of carbon serves as the positive electrode; a rod of zinc, as the negative electrode. The positive carbon electrode is placed in a porous cup which

is filled with a mixture of graphite and manganese dioxide. The function of the manganese dioxide is to serve as the depolarizing agent.

This cell is used for *open circuit work*, such as the ringing of door bells, etc. The E.M.F. of the Leclanche cell is about 1.4 volts.

319. The Dry Cell. The so-called dry cell, Fig. 264, is a modified form of the Leclanche cell. In reality it is not a dry cell at all, since it contains a moist paste consisting of ammonium chloride, zinc chloride, zinc oxide, and plaster of Paris. The E.M.F. generated is due to the action of the ammonium chloride upon the zinc electrode, which in this case forms the outer wall of the

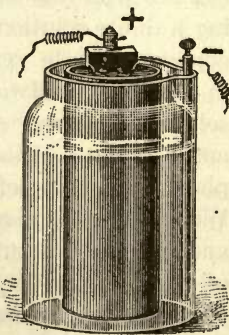


FIG. 263
Leclanche Cell

cell. The positive electrode is a carbon rod. The cell is hermetically sealed to prevent evaporation.

When the dry cell is new its current-producing power is high; with time, however, its internal resistance increases and its current is cut down proportionally. On account of the cheapness and convenience of these cells they are today more extensively used than any other type. The E.M.F. furnished is about the same as that of a Leclanche cell (1.4 volts).

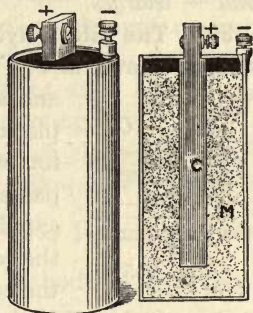
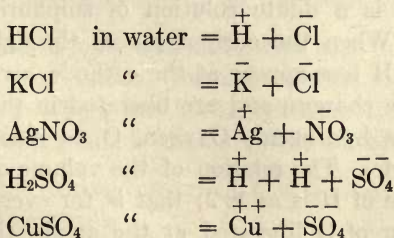


FIG. 264. — Dry Cell

CHEMICAL EFFECTS OF A CURRENT

320. The Dissociation Theory. If a salt, such as sodium chloride (NaCl), be dissolved in water, the greater part of it *dissociates*; that is, it breaks up into parts called *ions*, as follows:
 NaCl in $\text{H}_2\text{O} = \overset{+}{\text{Na}} + \bar{\text{Cl}}$. The symbol for the sodium atom with a $+$ sign above it, $\overset{+}{\text{Na}}$, is called the positive ion; $\bar{\text{Cl}}$ is called the negative ion. The $\overset{+}{\text{Na}}$ ion carries a $+$ charge of electricity; the $\bar{\text{Cl}}$ carries a $-$ charge.

The following chemical reactions illustrate a few of the simpler cases of ionization of acids, bases, and salts:



An *electrolyte* is a solution, similar to the above, which contains ions. It will be noted that when molecules dissociate into ions, there are always formed an equal number of + and - charges.

321. The Electrolytic Cell. Suppose that we have a cell such as shown in Fig. 265, consisting of two similar electrodes

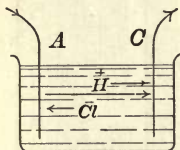


FIG. 265

and an electrolyte. Let the electrodes be of platinum and the electrolyte be a dilute acid, for example, HCl. Now if a current be passed through this cell in a direction indicated by the arrows, the + ions will go with the current and the - ions will go against the current. The electrode toward which the

+ ions go is called the *cathode*; the other electrode the *anode*. It is characteristic of H ions and metallic ions to go with the current; negative ions always go against the current. Such a cell as here described is called an *electrolytic cell*. It differs from a voltaic cell in this respect: *The voltaic cell is designed to furnish a current; the electrolytic cell is designed to electrolyze a solution. Electrolysis is the process by which the ions of a solution are separated by means of a current.*

322. The Decomposition of Water by Electrolysis. *Experiment.* In the decomposition of water by electrolysis we use a cell of a type shown in Fig. 266. The electrodes are of platinum, which is used because this metal is not acted upon by any acid. The electrolyte is a dilute solution of sulphuric acid in water. When the current passes through such a cell, the H ions appear at the cathode, give up their positive charges, and are liberated in the form of gaseous hydrogen. Oxygen, O, is liberated at the anode. The relation of the volume of O to the volume of H is as 1:2; that is, for every cubic centimeter of O liberated at the anode there are two cubic centimeters of H liberated at the cathode.

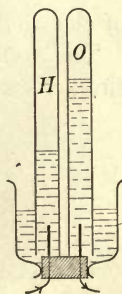


FIG. 266

323. Chemical Reactions in Electrolysis of Water. The chemical reactions which take place in the electrolysis of water containing sulphuric acid are quite complex, the nature of the reaction depending upon the E.M.F. applied. A full discussion of this subject is beyond the limits of an elementary text, it being sufficient to say that the object of adding sulphuric acid to the water is to increase the concentration of the ions and thus to make the solution more conducting.

Decomposition of the water occurs in this electrolytic process largely as a secondary reaction, as follows: The acid on being added to the water is dissociated into H^+ ions and SO_4^{--} ions. The H^+ ions are liberated at the cathode as hydrogen; the SO_4^{--} ions appear at the anode, giving up their negative charges and liberating oxygen, probably after this manner:



The sulphuric acid thus formed dissociates, forming new H^+ and SO_4^{--} ions.

324. Electrolysis of Copper Sulphate. Consider that we have an electrolytic cell, Fig. 267, in which the electrodes are of copper and the electrolyte a solution of copper sulphate, CuSO_4 . The salt dissociates

as follows: $\text{CuSO}_4 = \text{Cu}^{++} + \text{SO}_4^{--}$. The positive ions, Cu^{++} , are deposited upon the cath-

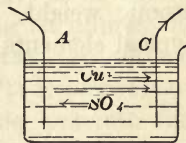


FIG. 267

ode; the negative ions, SO_4^{--} , unite with copper ions at the anode, forming CuSO_4 .

Thus for every copper ion discharged from the solution at the cathode, a copper ion is discharged into the solution at the anode, and the concentration of the Cu^{++} ions of the solution thus remains constant.

If platinum instead of copper electrodes are used the follow-

ing reactions will take place: At the cathode $\overset{++}{\text{Cu}}$ ions are discharged, thus copper-plating the platinum of that electrode.

At the anode $\overset{-}{\text{SO}}_4$ ions are discharged, and since these ions cannot react chemically with the platinum they react with the water, forming sulphuric acid, H_2SO_4 and liberating O, as in the case of the electrolysis of water.

325. The Laws of Electrolysis. The laws governing the deposition of ions by electrolysis were first announced by Faraday (1791–1867) and are now known as Faraday's laws of electrolysis. They are two in number and may be stated as follows:

I. *The amount of a substance deposited in an electrolytic cell is proportional to the strength of the current and to the time which it flows.* This means that if a given current flowing through an electrolytic cell for 1 hour deposits 1 gram of copper, then twice as much current flowing for 2 hours will deposit 2×2 or 4 grams of copper.

II. *If the same current flow through two or more cells in series, the amount deposited at the electrodes in each cell will be proportional to the chemical equivalent of the element deposited.* The chemical equivalent of an element is its atomic weight divided by its valence. The relation between the atomic weight, valence, and chemical equivalents of a few typical elements is shown in the following table:

Element	Atomic weight	Valence	Chemical equivalent
H	1	1	1
O	16	2	8
Cu	63	2	31
Ag	107	1	107

Thus if there be three electrolytic cells connected in series containing in order ions as follows, H, Cu, Ag, and the same current be passed through each cell, for every gram of hydrogen liberated in one cell there will be deposited in the second cell 31 grams of copper, and in the third 107 grams of silver. Appli-

cations of the laws and principles of electrolysis in the arts and sciences are very numerous, some of the more important being stated in the following topics.

326. The Electrolytic Refining of Copper. As obtained from its ores, copper contains a number of impurities which make it objectionable for certain kinds of electrical service. To remove these impurities the electrolytic process of refining is largely employed. A large piece of impure copper is suspended as the anode in a bath of copper sulphate, Fig. 268; a small piece of pure copper is used as the cathode. A current of proper strength is passed through the cell. The anode gradually dissolves and pure copper is deposited on the cathode.

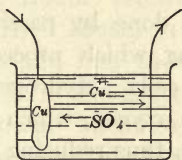


FIG. 268

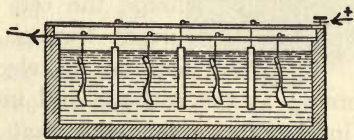


FIG. 269

327. Copper Plating and Electrotyping. In copper plating and electrotyping a bath of copper sulphate is employed. A piece of copper serves as the anode. The object to be plated is suspended as the cathode. In electrotyping an impression of the type after being set up is made in wax, the surface of which is coated with fine powdered graphite to render it conducting. The wax mold thus prepared is now put into the bath as the cathode, and a suitable deposit of copper made upon it.

328. Silver Plating. The silver plating of tableware, such as spoons, knives, forks, etc., Fig. 269, is a familiar illustration of the electrolysis of a silver salt. For such work a solution of silver cyanide is used as the electrolyte, since solutions of this salt give a smooth and compact deposit. The electrolysis of silver nitrate, $AgNO_3$, also furnishes a standard method of meas-

uring currents of electricity, as will be more fully explained later (Art. 332).

329. The Principle of the Storage Cell. A storage cell embodies the characteristics of both an electrolytic and a voltaic cell in that it may be used over and over again by being alternately charged and discharged. While being charged it acts as an electrolytic cell; on discharge it acts as a voltaic cell. The essential features of a cell of this type may be illustrated by means of a simple piece of apparatus, Fig. 270, consisting of two strips of lead immersed in dilute sulphuric acid. The first step is to charge the cell. This is done by passing a current through it, during which process it acts as an electrolytic cell. Hydrogen is

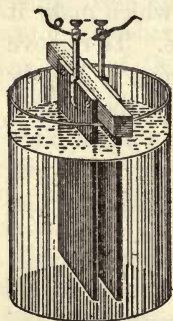


FIG. 270

liberated at the cathode and unites with oxygen, which may be in chemical union with that electrode, thus reducing it to bright metallic lead. Oxygen is liberated at the anode, uniting with the lead to form a reddish deposit of lead oxide. The cell is now charged, the anode consisting of lead oxide and the cathode of metallic lead.

The second step is to discharge the battery, during which process it acts as a voltaic cell. If it be connected to an electric bell the latter will ring vigorously for some time; that is, until the cell is discharged. On discharge the lead oxide is the positive electrode, the metallic lead the negative electrode. During discharge the lead oxide is reduced and the metallic lead of the other electrode is oxidized.

330. Storage Batteries and their Use. A storage battery consists of one or more storage cells, two types of which are now in general use: one is the lead cell, the other the Edison cell.

The commercial form of the lead cell is shown in Fig. 271. The electrodes consist of two lead plates, one metallic lead,

the other covered with lead peroxide, both being immersed in a dilute solution of sulphuric acid. The peroxide plate is reddish in color and is the + electrode. The E.M.F. of a lead cell is 2 volts. Since the internal resistance is very low, usually less than 0.1 ohm, this cell is capable of furnishing a high current. The lead cell should never be short circuited.

The Edison cell, Fig. 272, is of comparatively recent invention and is as yet not so thoroughly tested as is the lead cell. The electrolyte used in this cell consists of a dilute solution of caustic potash (KOH). Nickel is used as the + electrode and iron as the - electrode. The E.M.F. of the Edison cell is 1.2 volts.

Storage batteries do not, as is sometimes supposed, store up electricity; a storage battery is a device for storing energy. On charging the battery the energy of an electric cell is converted into potential energy represented by the oxidation of

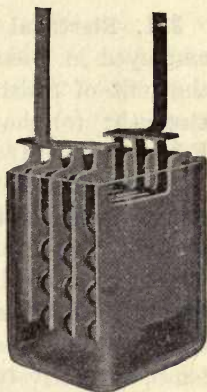


FIG. 271
Lead Storage Cell

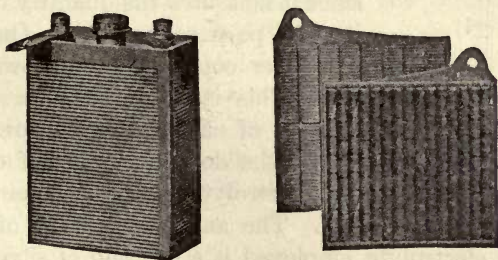


FIG. 272. — Edison Storage Cell, showing Nickel and Iron Electrodes

the positive electrode. Storage batteries are largely used today to furnish power for electric automobiles, and also in connection with electric lighting and power plants.

For further important information relating to storage batteries, see Supplement, 574 and 575.

UNITS OF ELECTRICAL QUANTITIES

331. Electrical Units. The four most important units employed in measuring electrical quantities are (a) the ohm, the unit of resistance; (b) the ampere, the unit of current strength; (c) the volt, the unit of potential difference and E.M.F.; and (d) the coulomb, the unit of quantity.

Nearly all the units employed in the measurement of electrical quantities have been named in honor of some celebrated physicist or chemist. The ampere, for example, was so named in honor of Ampère, a noted French physicist; the ohm after Ohm, a German physicist. Likewise the volt and coulomb were named in honor of Volta and Coulomb, respectively, the former an Italian and the latter a Frenchman.

✓ **332. The Ampere.** A standard and fundamental method of measuring a current of electricity is furnished by the electrolysis of silver nitrate, AgNO_3 . The electrolytic cell employed is called a silver voltameter, or better, a silver coulometer,

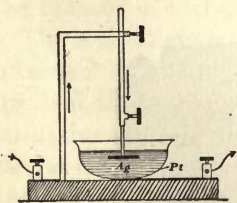


FIG. 273

since it measures the quantity of electricity that passes through it. One form of the silver coulometer is shown in Fig. 273. This is an electrolytic cell, consisting of a platinum bowl, which serves the double purpose of containing the electrolyte and acting as the cathode. The anode is a piece of pure silver. The electrolyte employed is a solution of silver nitrate, prepared according to standard specifications. The direction of the current is indicated by the arrows. Silver is deposited on the platinum cathode, the quantity thus deposited being determined by weighing the cathode (platinum bowl) both before and after the experiment. We define the unit of cur-

rent strength, the ampere, in terms of the quantity of silver deposited per second.

An ampere is that current which will deposit 0.001118 gram of silver in one second.

✓ **333. The Ohm.** Every conductor offers resistance to a current. *The unit of resistance is the ohm, which is defined as the resistance offered to an unvarying current of electricity by a column of mercury 106.3 centimeters in length, of uniform cross section, and having a mass of 14.4521 grams, at a temperature of 0°C .* The reason for selecting mercury as the standard metal in measuring the unit of resistance is (a) that it has a high resistance as compared with other metals and (b) it can be obtained in a very pure state by distillation.

Ohm discovered that for a given conductor the current strength is proportional to the E.M.F. This means that for a given conductor the resistance is independent of the strength of the current flowing through it, provided the temperature remains constant.

✓ **334. The Volt:** The unit of potential difference and E.M.F. is called the volt. *A volt is the electromotive force that will cause a current of one ampere to flow through a resistance of one ohm.* The difference of potential applied to the ordinary incandescent lamp, for example, is 110 volts.

335. The Coulomb. *A coulomb is the quantity of electricity conveyed in one second by a current of one ampere.* The current that flows through a 16 candle power carbon incandescent lamp when illuminated to full candle power is about $\frac{1}{2}$ ampere. A lamp burning for 4 hours will take $4 \times 60 \times 60 \times \frac{1}{2} = 7200$ coulombs.

MAGNETIC EFFECTS OF A CURRENT

336. Magnetic Field about a Current. It was early discovered that there existed a very close relationship between an electric current and magnetic lines of induction. That there exists a magnetic field about a wire carrying a current may be

shown in a very striking manner as follows: Pass a wire through a hole in a piece of cardboard or a glass plate upon which iron filings have been sprinkled. Now if the wire be connected to a source of E.M.F. and a rather strong current be passed through the circuit, the iron filings will arrange themselves in concentric lines about the conductor, thus showing that there is a magnetic field about the wire due to the current. The

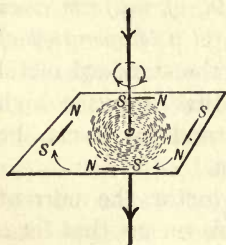


FIG. 274

direction of the lines of induction about the wire may be determined by placing a magnetic needle upon the plate, Fig. 274. If the current through the wire be reversed the direction of the lines of induction will be reversed, as shown by the reversal of the needle. The relation between the direction of the current and the direction of the magnetic lines of induction may be illustrated by grasping the wire with the right hand with the thumb in the direction of the current, in which case the fingers will represent the direction of the lines of induction.

337. Effects of a Current on the Magnetic Needle. *Experiment.* A magnetic needle always tends to set itself parallel to the direction of the lines of induction of the magnetic field in which it is placed, in such a way that the lines may be conceived of as entering the S-pole and coming out the N-pole. When a magnetic needle is placed in the earth's field it therefore takes a north-south position. Now if a wire carrying a current be brought near the needle and above it, with a current flowing in the direction indicated in Fig. 275, the needle will be acted upon by two magnetic fields, the earth's field in one direction and the magnetic field due to the wire in a direction at right angles to the earth's field. Two forces therefore act upon the needle, which takes a position representing the direction of resultant of these two forces. When the wire is above the needle, as shown in Fig. 275, the N-pole is deflected

toward the observer. When the wire is below the needle, Fig. 276, the current remaining in the same direction, the N-pole is deflected away from the observer.

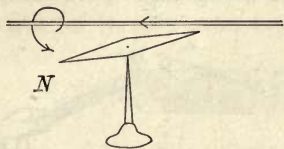


FIG. 275

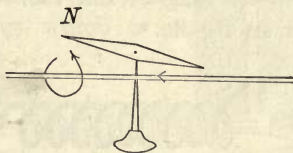


FIG. 276

338. Rule to Determine the Direction of Deflection of the Needle. Grasp the wire with the right hand, the thumb in the direction of the current, and the fingers will indicate the direction of the magnetic field about the wire, Fig. 277. The deflection of the N-pole will therefore always be in the direction of the fingers.



FIG. 277

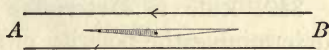


FIG. 278

EXERCISES. 1. Consider Fig. 278 with reference to direction of current and position of needle. Make drawings to illustrate the following cases, using the right hand rule to determine the deflection of the N-pole in each case: (a) Current in direction *BA* and above needle; (b) current in direction *BA* and below needle.

2. Consider that the wire carrying the current, Fig. 278, be placed beside the needle, the current flowing from *B* to *A*. Determine by the right hand rule the effect on the needle.

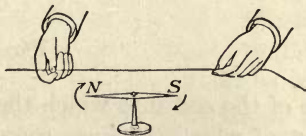


FIG. 279

3. Determine the direction of the current in the case of Fig. 279.

339. The Solenoid. A solenoid consists of a coil of wire of several turns, Fig. 280, which carries a current. When a current passes through the solenoid the coil acquires the properties of a magnet, one face or end being an N-pole and the other an S-pole.

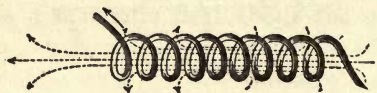


FIG. 280. — Solenoid

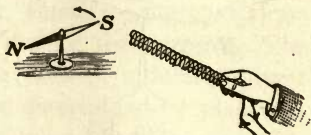


FIG. 281

Experiment. The polarity of a solenoid may be shown as follows: Pass a current through a number of turns of insulated wire, Fig. 281. Present one face of the coil to the N-pole of a magnetic needle; the needle is deflected in a given direction. Present the other face of the solenoid to the N-pole. The needle is now deflected in an opposite direction. This shows that a solenoid acts like a magnet, having an N- and an S-pole.

340. Rule to Determine the Polarity of a Solenoid. In determining the polarity of a solenoid we may again make use of the right hand rule. Grasp one or more wires in the right hand, the thumb being in the direction of the current, and the fingers will represent the direction of the lines of induction,

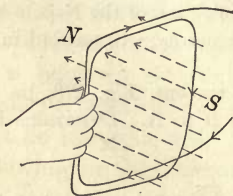


FIG. 282



FIG. 283

Fig. 282. The face of the coil into which the lines enter is the S-pole; the face out of which the lines come is the N-pole.

It is also sometimes convenient to make use of a second rule, as illustrated in Fig. 283. Grasp the solenoid with the

right hand, the fingers being in the direction of the current, and the thumb will indicate the position of the N-pole.

341. The Electromagnet. An *electromagnet* consists of a soft iron bar about which is



FIG. 284 — Electromagnet



FIG. 285

wrapped a number of turns of insulated wire, Fig. 284. The electromagnet, it will be observed, is nothing more than a solenoid having an iron core. The presence of the metal core in the coil increases enormously the strength of the magnetic field, since the iron offers a much easier path for the lines of induction than does the air.

An electromagnet of the horseshoe type is shown in Fig. 285.

342. Parallel Currents. *Experiment.* If two conductors be suspended as shown in Fig. 286, so that the lower ends dip into

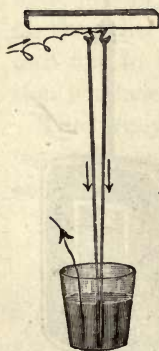


FIG. 286

mercury, and a current be allowed to flow, as indicated by the arrows, we will have the condition of parallel currents flowing in the same direction. The wires will be attracted.

If now the apparatus be adjusted so that the parallel currents flow in opposite directions, Fig. 287, the conductors will repel each other.



FIG. 287

The law of parallel currents may be stated as follows: *Parallel currents in the same direction attract;*

parallel currents in the opposite direction repel.

343. Explanation of Attraction and Repulsion of Parallel Currents. The attraction and repulsion of parallel currents may be understood by considering the magnetic fields in the

two cases. Fig. 288 shows the magnetic field about parallel currents in the same direction. Many of the lines of induction encircle both wires, and hence tend to bring them together.

In the case of magnetic fields due to parallel currents in the opposite direction, Fig. 289, the lines of induction of the two systems are crowded between the two conductors, and hence tend to force them apart.

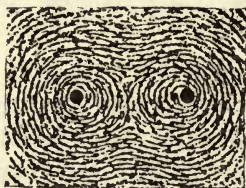


FIG. 288

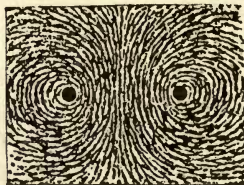


FIG. 289

ELECTRICAL MEASURING INSTRUMENTS

344. The Galvanometer. A *galvanometer* is an instrument for measuring small currents of electricity.



FIG. 290

One of the simplest forms is shown in Fig. 290.

When a current flows through the conductor, the

magnetic needle suspended within the coil is deflected. This is called a tangent galvanometer because the strength of current is proportional to the tangent of the angle of deflection. This form of galvanometer is not at present used very extensively. A much more common and convenient type is the d'Arsonval galvanometer, Fig. 291.

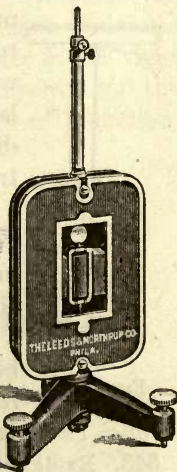


FIG. 291. — D'Arsonval Galvanometer

345. The d'Arsonval Galvanometer. The general principle upon which this instru-

ment works is shown in Fig. 292. A coil of fine wire is suspended between the poles of a horseshoe magnet in such a way that a current may enter at one point and leave at another. Now when the current flows through the coil one face becomes an N-pole, the other an S-pole, and as a result the coil swings about its axis due to the attraction of its poles for those of the permanent magnet. Attached to the coil is a pointer, or better still, a small mirror reflecting a beam of light. Thus, whenever a current flows through the instrument, its presence is indicated by the deflection of the coil. The great advantage of the d'Arsonval galvanometer over the tangent galvanometer lies not only in the fact that the former is more compact in construction and convenient in form than is the tangent galvanometer, but also that it is independent of the earth's field. The tangent galvanometer has to be set up in such a manner that its magnetic needle points north-south. The d'Arsonval instrument, on the other hand, having a very strong magnetic field of its own due to its permanent magnet, may be set up in any position whatsoever with respect to the earth's field.

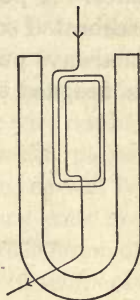


FIG. 292

The principle of the d'Arsonval galvanometer is very extensively employed in the construction of voltmeters and ammeters, Fig. 293.

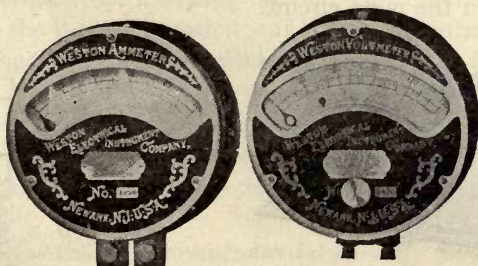


FIG. 293. — Ammeter and Voltmeter

346. The Ammeter. *An ammeter is an instrument for measuring current strength in amperes. It is really a galvanometer, usually of the d'Arsonval type, having a coil of very low resistance. A pointer and scale is provided, the latter of which is calibrated so as to indicate readings in amperes. An ammeter is always put in series with the circuit, the current of which it is designed to measure, Fig. 294.*



FIG. 294. — Ammeter in Series with Circuit

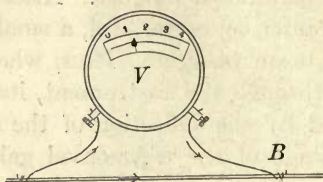


FIG. 295. — Voltmeter in Shunt

347. The Voltmeter. *The voltmeter is an instrument for measuring the difference of potential in volts. Like the ammeter it is also a d'Arsonval galvanometer, but differs from the ammeter in the fact that it is provided with a coil of high resistance and also that it is calibrated to give readings in volts. A voltmeter is put in parallel with the conductor over which the potential difference is to be measured, Fig. 295, and it is for this reason that voltmeters are constructed with coils of high resistance; that is, so that the instrument will draw only a relatively small current from the main circuit.*

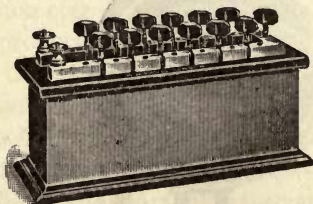


FIG. 296. — Resistance Box

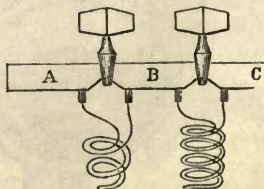


FIG. 297. — Resistance Coils

348. The Resistance Box. In measuring resistance it is desirable to have at hand a known resistance, such as is furnished by the *resistance box* shown in Fig. 296. Such a box contains a set of *resistance coils*. A resistance coil, Fig. 297, is a coil of wire having a definite known resistance. It is made by winding the wire in the form of a spiral, the two free ends being fastened to the metal plates *A, B, C*, which in turn are set in the resistance box. The object of winding the wire double is to prevent magnetizing effects when the current passes through the coil, and also to prevent self-induction, as will be explained in Art. 378. The best modern resistance coils are made of manganin wire (Supplement, 576), the resistance of which is practically unaffected by ordinary changes of temperature such as occur in the laboratory. These coils are mounted in boxes with their terminals connected to the brass plates as shown. Connection from one wire of the coil to the next is made by means of a metal plug. When the plugs are all in place the resistance of the box is practically zero. When a plug is withdrawn from the box the resistance offered is equal to that of the coil beneath the particular plug withdrawn.

Resistance boxes may be bought with coils varying in resistance from 0.1 to 1000 ohms, and even greater ranges.

OHM'S LAW AND ITS APPLICATIONS

349. The Laws of Resistance. The resistance of a conductor depends upon the following factors: (a) The length of the conductor; (b) its cross section; (c) kind of material used; and (d) the temperature. The laws of resistance may be stated as follows:

I. *The resistance of a conductor is directly proportional to its length.* For example, if 10 feet of a given wire have a resistance of 1 ohm, 20 feet of the same wire will have a resistance of 2 ohms.

II. *The resistance of a conductor is inversely proportional to its cross sectional area.* That is, the greater the cross sectional

area of a conductor, the less the resistance. Since the cross sectional area of a wire is proportional to the square of its diameter d , it is sometimes convenient to consider the resistance as inversely proportional to the square of the diameter, d^2 .

III. *The resistance of a conductor depends on the material of which it is composed.* The resistance of iron, for example, is more than six times as great as that of copper, for the same length and cross section.

IV. *The resistance of a metallic conductor increases as the temperature increases.* The hotter a wire becomes, the greater is its resistance. On the other hand, *the resistance of carbon and electrolytes decreases as the temperature increases.* The resistance of the carbon filament of a 110 volt 16 candle power incandescent lamp is, when cold, about 440 ohms; when hot (incandescent) about 220 ohms.

350. Discussion of the Laws of Resistance. The first three laws may be expressed in the form of an equation as follows:

$$R = k \times \frac{l}{d^2}$$

in which R is the resistance in ohms, l the length in feet, d is the diameter of the wire usually expressed in thousandths of an inch, and k a constant depending on the nature of the material of which the conductor is composed. The constant k is usually expressed in ohms per "mil-foot," a mil-foot representing a wire 1 foot in length and $\frac{1}{1000}$ of an inch in diameter.

The following are some values for k in ohms per mil-foot, taking the resistance of 1 mil-foot of silver at 20° C. as 9.5 ohms.

Silver, 9.5 ohms per mil-foot	Platinum, 70 ohms per mil-foot
Copper, 10.2 ohms per mil-foot	Manganin, 215 ohms per mil-foot
Iron, 61.5 ohms per mil-foot	Mercury, 570 ohms per mil-foot

Example. Find the resistance of 1000 feet of No. 20 copper wire having a diameter of 0.03 inch. *Solution:* $R = k \times \frac{l}{d^2}$; k

for copper from table above = 10.2; $l = 1000$ feet; since .03 inch
 $= \frac{30}{1000} = 30$ mils, $d = 30$ and $d^2 = 900$. Hence $R = \frac{10.2 \times 1000}{900}$
 $= 11.33$ ohms.

351. Resistance of Conductors in Series. When conductors are joined end to end as shown in Fig. 298, they are said to be connected in *series*. The resistance of a number of conductors connected in series is equal to the sum of the individual resistances; thus, $R = r_1 + r_2 + r_3 \dots$

Example. Three wires having resistances of 5, 10, and 15 ohms respectively are connected in series. Find the total resistance of the combination. *Solution:* $R = 5 + 10 + 15 = 30$ ohms.

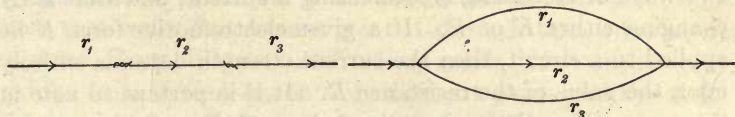


FIG. 298. — Conductors in Series FIG. 299. — Conductors in Parallel

352. Resistance of Conductors in Parallel. When two or more conductors are connected as shown in Fig. 299 they are said to be in *parallel*. It may be demonstrated that the resistance R of two or more conductors in parallel may be expressed by an equation of the following form:

$$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} \dots$$

Example. Let r_1 , Fig. 297, be a resistance of 5 ohms, r_2 10 ohms, and r_3 15 ohms. Find the resistance of the three wires thus connected in parallel. *Solution:* $\frac{1}{R} = \frac{1}{5} + \frac{1}{10} + \frac{1}{15}$,
hence $R = 2.7$ ohms.

353. Ohm's Law. One of the most important generalizations in electricity is that known as *Ohm's law*, which may be stated as follows: *The current in amperes, I , is equal to the*

electromotive force in volts, E , divided by the resistance in ohms, R . The equation for this law is

$$I = \frac{E}{R}$$

which implies that the current from any source, such as a battery, is directly proportional to the voltage and inversely proportional to the resistance; that is, for a given resistance the greater the E.M.F. the greater the current; and on the other hand, for a given E.M.F. the greater the resistance the less the current.

354. Current Strength in a Circuit. We learn from Ohm's law that, so far as direct currents are concerned, there are only two ways of increasing or decreasing a current, and that is by changing either E or R . If a given electromotive force E be applied to a circuit, then the current strength depends entirely upon the value of the resistance R . It is important to note in this connection that when the values of E and R are once fixed, the current strength is the same in all parts of the circuit. Thus if ammeters A and A' be placed in the same circuit, Fig. 300, it will be found that, for a given electromotive force and resistance, the current strength, as registered by the instrument, will be the same at both points.

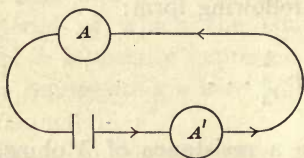


FIG. 300

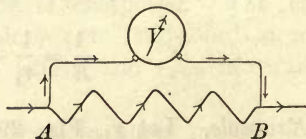


FIG. 301

355. Fall of Potential by Ohm's Law. Ohm's law may be stated in a very convenient form,

$$E = IR$$

in which E , the fall of potential between two points on the conductor, is equal to the product of the current flowing through

the conductor multiplied by the resistance of the conductor between the given points. This equation contains three factors; therefore, when two of these quantities are given, the third may readily be found. Ohm's law, then, furnishes a standard method of determining (a) the fall of potential between the two points and (b) the resistance of a conductor.

Example. To illustrate the use of this equation, let us consider the conductor shown in Fig. 301. The current I flowing through the wire is 2 amperes; the resistance of the conductor from A to B is 5 ohms. The fall of potential therefore is $E = IR = 2 \times 5 = 10$ volts, which is the value registered by the voltmeter.

356. Fall of Potential over Conductors in Parallel. Suppose that water flow from a point A through three trenches to a point B on a lower level. Now while the trenches may extend from A to B by entirely different paths and the water flowing in any trench may be entirely different in quantity from that of any of the other trenches, yet we readily comprehend that the difference of pressure between the two points A and B is the same, no matter what path we consider. Suppose now that a current from a point A at high potential flow over three paths or conductors to a point B of low potential. As in the case of the trenches, the conductors may be quite different in length and the currents of electricity flowing in each may also differ from each other, yet the fall of potential from A to B is the same, no matter which path we consider. That is, in the case of conductors in parallel the fall of potential over each conductor is the same, and furthermore, the fall of potential over each conductor is the same as the fall of potential from A to B obtained by multiplying the total current by the total resistance between these points.

Example. Three conductors, 4, 6, and 12 ohms respectively, connect the points A and B . A current of 6 amperes flows from A to B , a part passing through each conductor. Find (a) the

fall of potential from A to B ; (b) the current through each wire.
Solution: (a) The current from A to $B = 6$ amperes; the resistance from A to $B = 2$ ohms. Therefore, the fall of potential from A to $B = 6 \times 2 = 12$ volts. (b) Now since the fall of potential from A to B , as just found, is 12 volts, the fall of potential over any one of the three paths is also 12 volts. Hence the current in the first path will be $\frac{12}{4} = 3$ amperes; the current in the second path $\frac{12}{6} = 2$ amperes; the current in the third path $\frac{12}{12} = 1$ ampere. The total current in all three paths $= 3 + 2 + 1 = 6$ amperes.

357. Resistance by Ohm's Law. The equation $E = IR$ suggests also a method of determining the resistance of a conductor, provided the current I and the voltage E be known; thus, $R = E/I$. In order to find E and I experimentally it is necessary to use the voltmeter and the ammeter; for this reason the method is sometimes spoken of as the voltmeter-ammeter method of measuring resistance.

Example. Suppose we desire to find the resistance of a lamp by the voltmeter-ammeter method. An ammeter is put in series with the lamp and a voltmeter connected across its terminal, Fig. 302. The reading of the ammeter is $\frac{1}{2}$ ampere and that of the voltmeter 110 volts. Find the resistance of the lamp. *Solution:* $R = E/I = 220$ ohms.

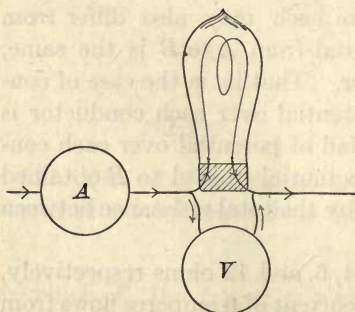


FIG. 302

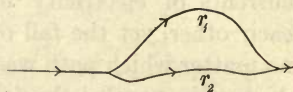


FIG. 303

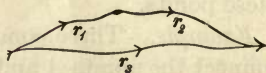


FIG. 304

EXERCISES. 4. Find the resistance of 10 miles of iron telephone wire having a diameter of 150 mils.

5. Consider Fig. 303. The resistance of r_1 is 15 ohms, that of r_2 10 ohms. Find the resistance of the two conductors in parallel.

6. Three wires, the resistance of which are 2, 4, and 6 ohms respectively, are connected in parallel. Find the resistance of the system.

7. The three wires of exercise 6 are connected as in Fig. 304. Find the resistance of the system.

8. Given three incandescent lamps, the resistance of each when hot being 220 ohms. Find the resistance (a) when the three are connected in series; (b) when connected in parallel.

9. Two conductors, r_1 of resistance 2 ohms, r_2 8 ohms, are put in parallel. A current of 10 amperes flows through ammeter A , Fig. 305. What current flows through (a) r_1 ? (b) through r_2 ? (c) through ammeter A' ?

10. Find the fall of potential over r_1 of exercise 9; (b) the fall of potential over r_2 .

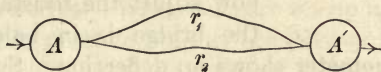


FIG. 305

358. Resistance by the Wheatstone Bridge Method. We have just discussed a method of determining resistance by the use of Ohm's law; that is, in determining R from E and I . Another very useful method is known as the Wheatstone bridge method. Wheatstone's bridge, so named after its inventor, Sir Charles Wheatstone, is a device for measuring a resistance by comparing it with a known resistance. The principle of the bridge is shown in Fig. 306, in which R_1 , R_2 , R_3 , R_4 represent resistances. A galvanometer G is connected to the points C and D ; a battery to the points A and B . When the bridge is in balance, the fall of potential (RI) on the conductor AC is

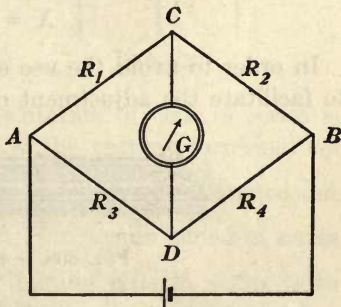


FIG. 306

equal to that along the conductor AD , and the fall of potential along CB is equal to that along DB , no current flows through the galvanometer. In other words, the bridge is in balance when the galvanometer shows no deflection. When this condition is realized, $R_1:R_2 = R_3:R_4$.

A simple demonstration of the principle of the bridge may be shown by means of Fig. 307. Suppose that it is desired to find

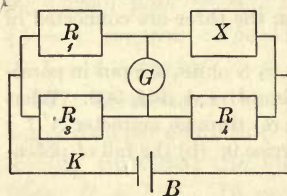


FIG. 307

the resistance of the coil of wire X . Three resistance boxes, R_1 , R_3 , R_4 , are placed in the three arms of the bridge as shown, X being the fourth arm. Let the resistance in R_3 be 10 ohms and that in R_4 100 ohms. We now adjust the resistance in R_1 until the bridge is in balance; that is,

until the galvanometer shows no deflection. Suppose that R_1 is 25 ohms, then by means of the equation we now find the value of X as follows:

$$\begin{aligned} R_1: X &= R_3: R_4 \\ 25: X &= 10: 100 \\ X &= 250 \text{ ohms} \end{aligned}$$

In order to avoid the use of three resistance boxes and also to facilitate the adjustment of the bridge, a device known as



FIG. 308.—Slide Wire Bridge

a slide wire bridge is used, Fig. 308, in which only one resistance box is required, a divided wire taking the place of the other two.

359. Methods of Joining Cells. Ohm's law may be applied to determine the best method of joining the cells of a battery.

The current furnished by a battery of one or more cells is determined by the electromotive force E and by the resistance of the system. The resistance of a coil is made up of two parts, that of the wires, etc., connected to the poles, called the external resistance R , and that of the battery itself, called the internal resistance r . The internal resistance of a battery depends upon the nature of the materials of which it is made, including electrodes and electrolyte, and upon the size of the plates; the larger the plates the less the resistance. It is important to keep in mind, in this connection, the fact that the E.M.F. of a cell is independent of the size of the plates.

The cells of a battery may be connected in two ways: (a) in series and (b) in parallel.

360. Cells in Series. When cells are set up in *series* the connecting wires join positive pole to negative pole, as shown in

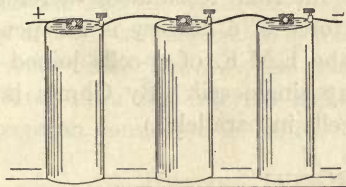


FIG. 309. — Cells in Series

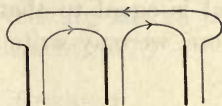


FIG. 310

Fig. 309. A diagrammatic representation of cells in series is shown in Fig. 310. By Ohm's law the current furnished by one cell is $I = \frac{E}{R + r}$, in which R is the external resistance and r the internal resistance of the cell; for n cells joined in series $I = \frac{nE}{R + nr}$. Thus the effect of joining cells in series is to make the total electromotive force and internal resistance respectively n times that of a single cell.

361. Cells in Parallel. When cells are connected in *parallel*, all the positive electrodes are joined together, and likewise all the negative electrodes, Fig. 311. The diagrammatic represen-

tation of cells in parallel is shown in Fig. 312. The effect of connecting a battery in parallel is equivalent to producing a single cell, having an E.M.F. equal to one of the original

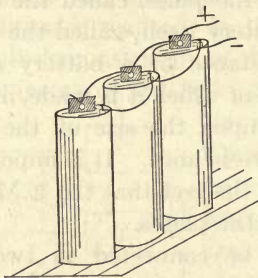


FIG. 311. — Cells in Parallel

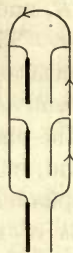


FIG. 312

cells, the plates of which are n times as large as those of any one of the original cells and the internal resistance, therefore, r/n . Since the electromotive force of a battery is independent of the size of the plates, the E.M.F. of n cells joined in parallel is equal to that of any single cell. By Ohm's law, therefore, we may write for n cells in parallel

$$I = \frac{E}{R + r/n}$$

362. The Advantage of Cells in Series and in Parallel. The relation of the current I to the external resistance R for cells connected in series and in parallel may be demonstrated most satisfactorily by means of examples. Given three cells the electromotive force E of each 1 volt, the internal resistance r of each 3 ohms.

Example. Find the current furnished through an external resistance R of 21 ohms (a) for a single cell; (b) when the cells are joined in series; and (c) in parallel.

Solution:

(a) *Single cell*, $I = E/(R + r) = \frac{1}{24} = 0.041$

(b) *Series* $I = nE/(R + nr) = 3/(21 + 9) = 0.100$

(c) *Parallel* $I = E/(R + r/n) = 1/(21 + 1) = 0.045$

It therefore appears that when the external resistance R is large in comparison with the internal resistance r , as in this case, the series arrangement gives a current nearly three times as great as that of one cell, while the parallel method of joining gives a current but very little greater than that of a single cell.

Example. Find the current furnished through a resistance R of 0.1 ohm (a) for a single cell; (b) when the cells are connected in series; (c) in parallel.

Solution :

(a) Single cell, $I = E/(R + r) = 1/3.1 = 0.32$

(b) Series $I = nE/(R + nr) = 3/9.1 = 0.33$

(c) Parallel $I = E/(R + r/n) = 1/1.1 = 0.91$

It is evident from a consideration of the above examples that when the external resistance R is less than the internal resistance r of a single cell, the method of joining cells in parallel is to be preferred. Since, however, the external resistance is nearly always greater than the internal resistance, cells are almost without exception connected in series. (Supplement, 577.)

HEATING EFFECT OF A CURRENT

363. The Electric Current as a Heating Agent. Whenever a current of electricity flows through a conductor heat is devel-

oped. The case that is most familiar is that of the heating of the fila-



FIG. 314



FIG. 313

ment of an incandescent lamp. Other illustrations of the heating effect of a current are exemplified in the use of the electric flatiron, Fig. 313, the electric soldering iron, Fig.

314, and similar appliances. Electric currents are also used in some places for cooking, and occasionally for the heating of rooms.

364. The Laws of Heat Development by a Current. By means of a simple calorimeter, Fig. 315, in which a current of electricity was passed through a wire immersed in a nonconducting fluid, Joule was able to determine the relation of the number of heat units H , developed by the current I flowing through a resistance R in the time t . This relation is expressed in the following laws:

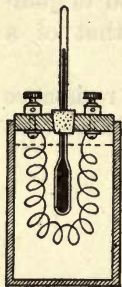


FIG. 315

I. *The heat is proportional to the time which the current flows.*

II. *The heat is proportional to the resistance of the conductor.*

III. *The heat is proportional to the square of the current.* That is, if a current of 1 ampere develops 1 unit of heat per second, then a current of 2 amperes will develop 4 units of heat per second.

These laws may be expressed by the equation

$$H = I^2 \times R \times t \times 0.24$$

in which H is the heat in calories, I the current in amperes, R the resistance in ohms, and t the time in seconds. *The constant 0.24 was determined by experiment and is the factor by which it is necessary to multiply in order to express the result in calories.*

Example. A current of 2 amperes flows through a conductor having a resistance of 5 ohms for 10 minutes. Find the heat developed in calories.

Solution:

$$\begin{aligned} H &= I^2 \times R \times t \times 0.24 = 4 \times 5 \times 10 \times 60 \times 0.24 \\ &= 2880 \text{ calories.} \end{aligned}$$

365. The Incandescent Lamp. At the present time the most important commercial application of the heating effect of a current is in the production of light, as in the case of incandescent and arc lighting systems. In the incandescent lamp

a filament of some nonfusible substance is enclosed within a glass bulb, from which the air is thoroughly exhausted. The object of removing the air from the bulb is twofold: (a) it prevents the burning out of the filament due to the presence of oxygen, and (b) it prevents conduction of heat from the filament to the glass. In a vacuum very much less heat is transmitted from the incandescent filament to the glass bulb than would be the case if a gas were present; for this reason the more nearly perfect the vacuum, the greater the intensity of the light.

The incandescent lamps are used mainly for indoor lighting, although in some cases they are employed for street lighting purposes, Fig. 316.

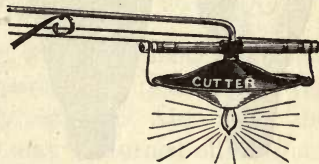


FIG. 316

The essential parts of an incandescent lamp are shown in Fig. 317. The current is conducted to and from the lamp by means of copper wires *cc*. It is conducted through the glass by means of short platinum wires *pp*, which are somewhat exaggerated in the figure for purposes of illustration. The object of using platinum is that this metal has the same coefficient of expansion as glass, and therefore may be sealed into glass without cracking the latter on cooling. The filament consists of some nonfusible substance which in being heated to incandescence furnishes the light.

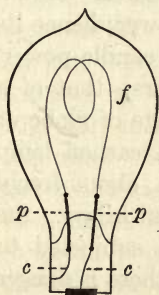


FIG. 317

There are at present on the market two general types of incandescent lamps: (a) those having carbon filaments, Fig. 318, and (b) those having metal filaments, as for example, tungsten, Fig. 319.

366. Comparison of Carbon and Tungsten Lamps. (a) The filament of a carbon incandescent lamp consists of an espe-

cially prepared thread of carbon; that of the tungsten lamp is made of tungsten, a metal which is capable of being drawn out into fine flexible wires and which may be heated to incandescence without melting.



FIG. 318



FIG. 319

(b) The carbon filament lamp is somewhat the cheaper of the two, but for a given current its candle power is considerably less than that of the tungsten lamp. It has been demonstrated experimentally that when two given lamps are consuming the same amount of electrical energy, the candle power of the tungsten lamp is nearly three times that of

the carbon lamp. For example, a 16 candle power carbon lamp on a 110 volt circuit takes a current of about $\frac{1}{2}$ ampere. The power expended (EI) is therefore $\frac{1}{2} \times 110 = 55$ watts. The expenditure of energy of such a lamp per candle power is therefore $55/16 = 3.4$ watts per candle power. Now a 40 watt tungsten lamp gives about 32 candle power; hence its expenditure of energy is $40/32 = 1.25$ watts per candle power. (c) The life of a carbon lamp is about 800 hours; that of a tungsten lamp, barring accidents such as breakage of globe or filament, an indefinite number of hours. (d) A carbon lamp has an advantage in that it may be moved about freely and subjected to jars, while incandescent, without injury; the tungsten lamp, on the other hand, cannot be subjected to very rough treatment while incandescent, since there is danger of injuring the metal filaments which are quite soft while hot.

367. Incandescent Lamp Circuits. Incandescent lamps are in general connected in parallel between the mains which lead from the dynamo (direct or alternating) or from the low voltage side of a transformer (Art. 392). The method of connecting incandescent lamps in parallel is shown in Fig. 320. Each lamp of a circuit may be turned on or off by means of a

key in the socket; all the lamps of the circuit may be turned on or off by means of a switch *S*. The resistance of the incandescent lamp is comparatively high, that of the 16 candle power

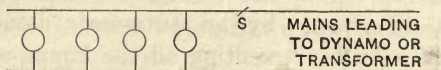


FIG. 320

110 volt carbon filament lamp being, when hot, about 220 ohms. When the lamps are connected in parallel the resistance of the system, however, is very materially reduced. Also, when the lamps are in parallel one or more may be turned off without seriously disturbing the rest of the circuit.

368. The Arc Lamp. The essential features of an arc lamp consist of two sticks of carbon, the ends of which touch. When a current is passed through the line the carbon points are drawn apart for a short distance, usually by means of an electro-magnet connected with the lamp. (Supplement, 578.) The current passes across the air gap there formed and heats the tips of the carbons to incandescence. One carbon, Fig. 321, is called the positive carbon and the other the negative. In the space between the carbons there is formed a volatilized carbon arc which serves as a conductor from one point to the other; it is called the electric arc because of its curved shape. The positive carbon is very much the hotter of the two and furnishes the greater part of the light. In the positive carbon there is a depression which is called the crater. The temperature of this crater when the lamp is heated is about 3500°C. , which is probably the highest temperature attainable by present methods.

FIG. 321
Electric Arc

369. Arc Lamp Circuits. In operating arc lighting systems the lamps are put in series, as indicated by the diagram of Fig. 322. If one lamp should go out provision is made that

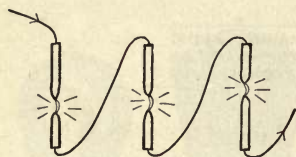


FIG. 322

the current be conducted around it by an automatic device, thus preventing all the lamps on the circuit being put out of commission. The ordinary arc lamp requires a difference of potential between the carbons of about 50 volts; the current

required to operate the lamp is from 4 to 10 amperes.

370. Kinds of Arc Lamps. In the *open arc* the carbons burn in the air. In this case the positive carbon wastes away about twice as fast as the negative, and both are consumed much more rapidly than if they were enclosed in some non-combustible medium. To add to the length of life of the carbon, the so-called enclosed arc lamp is employed.

In the *enclosed arc lamps*, Fig. 323, the carbons are placed within a small globe which is nearly air tight. After the lamp has been burning for a short time all the oxygen within the globe is consumed, and the carbons then burn in an oxygen free gas, mainly carbon dioxide. In this form of arc lamp the consumption of the carbon is very materially decreased, but the luminous efficiency of the lamp is also decreased.

The *flaming arc*. In the ordinary arc lamp described above most of the light comes from the positive carbon, very little being given out by the arc. In lamps of the flaming arc type the carbons contain a mixture of lime, magnesia, and other substances, which give to the arc its brilliant flaming character. In such lamps the arc itself is the chief source of light.



FIG. 323

371. Fuse Wires and Plugs. Advantage is taken of the

heating effect of a current in the manufacture of fuse wires and plugs, which are devices for automatically breaking the circuit in case, for a given system, the current becomes dangerously high. Fuse wires and fuse plugs are made of some high resistance material which has a low melting point. The fuse plug, Fig. 324, is so constructed as to be easily slipped in or out of a circuit. It consists of a high resistance conduc-



FIG. 324. — Fuse Plug

tor of such a nature that it will melt at a given current strength and thus break the circuit. Suppose, for example, that a fuse wire or plug be placed in a circuit containing a piece of apparatus, the maximum carrying capacity of which is 2.5 amperes, but which is designed to be operated, under ordinary conditions, with a current of 2 amperes or less. If now for any reason the current should tend to rise above the carrying capacity of the instrument, the fuse wire would melt at 2 amperes and thus save the apparatus from burning out.

In dwelling houses in which an incandescent lighting system is used there is, in general, a fuse box containing fuse wires or plugs for each division of the lighting circuit. The capacity of these fuses is usually from 5 to 10 amperes; that is, they are designed to melt when the current much exceeds these values. Since the melting or "blowing" of a fuse is always accompanied by the formation of an electric arc which is likely to set fire to nearby inflammable material, fuses should always be enclosed in fireproof receptacles.

POWER EXPENDED BY A CURRENT

372. Electric Power. The power expended by the electric current is expressed in watts, or more often in kilowatts. A watt, as defined in mechanics, represents the expenditure of energy at the rate of 10,000,000 ergs per second; a kilowatt is 1000 watts. In order to determine the power expended by an elec-

tric current it is necessary to know two things: (a) the current strength, (b) its voltage. This relation may be expressed as

$$\text{watts} = \text{volts} \times \text{amperes} = EI$$

It must be borne in mind that when we speak of the watt and the kilowatt these terms refer to units of power, which represent the expenditure of energy per unit of time. A 40 watt lamp is a lamp which consumes electrical energy at the rate of 40 watts; that is, 400,000,000 ergs per second.

373. The Expenditure of Electrical Energy by a Current. Since the watt and kilowatt represent the expenditure of energy per second, it follows that if we desire to find the total energy expended by a current in a given time, we must multiply the power (watts or kilowatts) by the time which the current flows. The units thus employed to express the total energy expended are the *watt hour* and *kilowatt hour*. A watt hour

represents an expenditure of energy at the rate of one watt for one hour. Since 1 watt is equivalent to 10,000,000 ergs per second, a watt hour is therefore equal to $10,000,000 \times 60 \times 60$ ergs = 36×10^9 ergs.

374. The Watt-Hour Meter.

The *watt-hour meter* is an instrument for summing up the total energy delivered to an electric circuit. Such meters may be made to operate on either direct or alternating currents. The mechanism of a watt-hour meter is essentially that of a small motor,

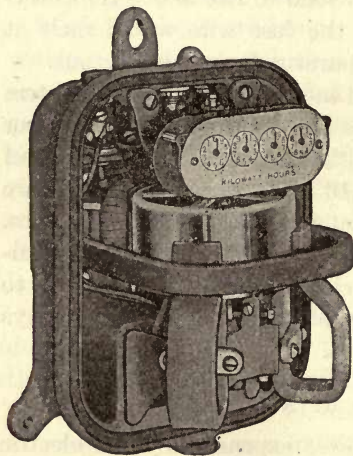


FIG. 325. — Kilowatt-hour Meter

the armature of which revolves at a speed proportional to the rate at which electrical energy is passing through it. The

armature is geared to recording dials, arranged like the dials on a gas meter which register the number of kilowatt hours of energy which pass through the meter.

The instrument shown in Fig. 325 records the electrical energy in kilowatt hours.

Example. A current of $\frac{1}{2}$ ampere under a pressure of 110 volts flows through an incandescent lamp for 5 hours. (a) Find the power expended in watts. (b) Find the energy expended in watt hours. (c) Find the energy expended in kilowatt hours. (d) Find the total energy expended in ergs.

Solution: (a) $Watts = EI$; hence $110 \times \frac{1}{2} = 55$ watts. (b) $Watt\ hours = watts \times time\ in\ hours = 55 \times 5 = 275$ watt hours. (c) 1 kilowatt = 1000 watts; therefore 275 watt hours = 0.275 kilowatt hour. (d) 1 watt represents the expenditure of energy of 10,000,000 ergs per second; hence the total energy expended in ergs = $55 \times 5 \times 60 \times 60 \times 10,000,000 = 99 \times 10^{11}$ ergs.

EXERCISES: 11. Given an incandescent lamp of 220 ohms resistance across the terminals of which is impressed an E.M.F. of 110 volts, giving rise to a current of $\frac{1}{2}$ ampere which flows for 2 hours. Find the heat in calories.

12. Considering the data of exercise 11, find the power expended on the lamp in (a) watts, (b) kilowatts.

13. Find the total electrical energy expended during the 2 hours in (a) watt hours; (b) kilowatt hours.

14. Find the total energy expended upon the lamp (exercise 12) in (a) ergs; (b) joules (Art. 100).

15. What will be the cost of running this lamp for 2 hours at the rate at which electrical energy is sold in your town?

CHAPTER IX

ELECTROMAGNETIC INDUCTION

INDUCED ELECTROMOTIVE FORCE

375. Faraday's Experiment. *Experiment.* If a magnet be thrust into a coil of wire the ends of which are connected to a galvanometer, Fig. 326, the needle will be deflected in a given direction; when the magnet is withdrawn from the coil, the

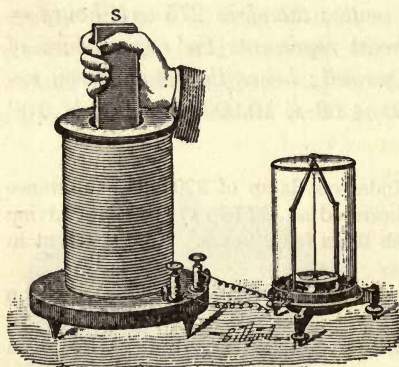


FIG. 326

needle will be deflected in the opposite direction. The current which flows through the coil and galvanometer when the magnet is being thrust in or pulled out is called an induced current, and the electromotive force developed by the motion of the magnet is called an induced E.M.F.

This induced electromotive force and resulting induced current is caused by the *cutting of the lines of magnetic induction across the wires* of the coil. If a magnet be thrust into a coil and held stationary, *no current flows so long as the magnet is at rest*. The induced E.M.F. manifests itself only while the magnet is in motion; that is, while there occurs an increase or decrease of the lines of induction threading through or cutting across the coil. It is important to note that an induced current flows only while the magnet is in motion and the coil is closed. If the coil be open while the magnet is in motion

there will occur in the wire, as before, an induced E.M.F., but no current. Induced currents always occur as a result of induced electromotive forces.

This experiment was first performed by Faraday in 1831. The relation of magnetism to electricity, as here shown, is known as the phenomenon of electromagnetic induction, upon which basis nearly all modern electrical industries have been developed.

376. Relation of the Lines of Induction to the Induced E.M.F. We have seen, from the preceding experiment, that when lines of magnetic induction cut across a wire there is set up in the conductor an induced E.M.F. which, if the conductor be closed, gives rise to an induced current. We have also learned that when a current flows through a conductor, lines of magnetic induction are set up in the medium around the wire. That is, currents give rise to magnetic lines of induction, and, on the other hand, the motion of magnetic lines of induction may give rise to induced electromotive forces and induced currents. It is important, therefore, to know the relation which exists between the direction of motion of the lines of induction and the direction of the induced E.M.F. There are two rules which are commonly employed to determine this relation as follows:

1. For the case of a circular conductor the following rule is serviceable. Consider that the N-pole of a magnet is thrust into a coil of wire, Fig. 327, and that the observer is in such a posi-

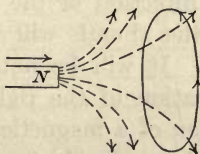


FIG. 327

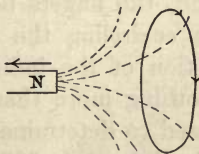


FIG. 328

tion as to look in the direction of the lines of induction, that is, from the S- to the N-pole, at the instant the magnet is thrust

into the coil or withdrawn. When the N-pole is thrust into the coil there is an increase of the lines of induction threading through the coil which gives rise to an *indirect* induced E.M.F. as shown by the arrows in Fig. 327. When the N-pole is withdrawn there is a decrease of the lines of induction which give rise to a *direct* induced E.M.F., Fig. 328. The words direct and indirect as here used refer to the motion of the hands of a watch or clock. Direct means clockwise; indirect, counter-clockwise. This rule may easily be remembered if it be kept in mind that *i* stands for *increase* and also for *indirect*; likewise *d* stands for *decrease* and also for *direct*.

2. A second rule for determining the direction of the induced E.M.F. is as follows: Suppose that a conductor *AB* move downward through a magnetic field, Fig. 329, cutting across the lines of induction. The direction of the induced E.M.F.

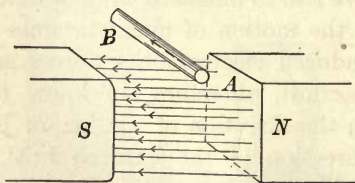


FIG. 329

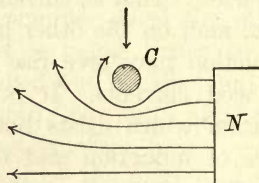


FIG. 330

in the conductor is from *A* to *B*. Each line on being cut may be conceived of as tending to wrap itself around the conductor, as shown in Fig. 330. Now if we grasp the wire with the right hand, the fingers being in the direction of the lines of induction encircling the conductor, the thumb will indicate the direction of the induced E.M.F. It will be noted that this is nothing more than the application of the right hand rule as used to determine the deflection of a magnetic needle, as explained in Art. 338. This right hand rule is of great importance because of its wide application in connection with the study of electromagnetic apparatus.

In text-books on electricity the following convention has

been adopted with reference to the direction of the E.M.F. Looking at the end of a conductor, a cross, representing the feathered end of an arrow, indicates an E.M.F., or a current flowing away from the observer, that is, into the paper; a dot, representing the point of an arrow, indicates an E.M.F. or current directed out of the paper and toward the observer. In Fig. 331 there is shown the relation of the direction of the lines of induction about the conductor to the direction of the induced E.M.F., in one case in and the other out.



FIG. 331

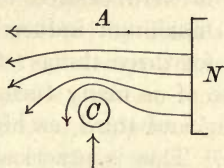


FIG. 332

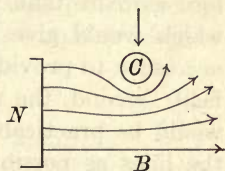


FIG. 333

EXERCISES: 1. A conductor C , Fig. 332, moves through the magnetic field from C to A . Will the induced E.M.F. be directed toward or from the observer; that is, will it be in or out?

2. What will be the direction of the induced E.M.F. if the conductor of Fig. 333 move from C to B ?

3. Find the direction of the induced E.M.F. when the conductor C , Fig. 334, moves in the direction (a) C to A ; (b) C to B ; (c) C to F ; (d) C to G ; (e) D to E .

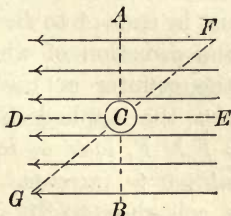


FIG. 334

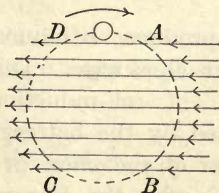


FIG. 335

4. Find the direction of the induced E.M.F. when the conductor, Fig. 335, moves through the field (a) from A to B ; (b) C to D . At what two points does the direction of the induced E.M.F. change?

377. Value of the Induced E.M.F. The electromotive force induced in a circuit depends upon the number of lines cut per unit of time. Now the number of lines cut per second depends, in turn, upon three factors: (a) the number of lines in the field, (b) the number of conductors cutting the lines, and (c) the speed at which the cutting occurs. In the case of a magnet thrust into a coil, the number of lines cut per second will depend upon the pole strength of the magnet, the rate at which it is moved, and the number of turns of wire in the coil. It is therefore evident that if it were desired to design an apparatus which would give a maximum induced E.M.F., it would be necessary to provide for three things: first, a strong magnetic field; second, the use of as many turns of wire in the coil as would be practicable; and third, as high a rate of cutting of the lines as possible. This is practically the problem which presents itself in the designing of many pieces of electromagnetic apparatus, such as certain types of dynamos.

378. Self-Induction. Consider Fig. 336. When the key is closed a current from the battery begins to flow around the circuit. This gives rise to lines of induction in the direction *A* to *B*. Now the appearance of the lines of induction in the coil has the same effect as if an N-pole were thrust in from *A* to *B*, which

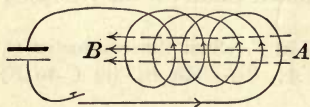


FIG. 336

would produce an induced E.M.F. the direction of which is counter clockwise. This is called the counter or the back E.M.F. of self-induction; it opposes the applied E.M.F. furnished by the battery. *The back E.M.F. lasts as long as the lines of induction in the coil continue to increase.* This explains why the current in such a coil rises to its maximum value slowly; it is due, in other words, to the counter E.M.F. of self-induction.

In a like manner, when the key is opened and the current broken, the lines of induction drop out of the coil, *thus having*

the same effect as the withdrawing of a magnet. This again produces an E.M.F. of self-induction which in this case tends to prolong the current after the circuit is broken.

Thus it is seen that, when a current flowing through a coil is changing in value, that is, increasing or decreasing, there is present in the coil a counter E.M.F. of self-induction, which tends to oppose the increase of the current at the instant the circuit is closed, and which likewise tends to prolong the current after the circuit is broken.

379. Lenz's Law. This opposition to change in an electromagnetic system is formulated by Lenz's law, which may be stated as follows: *When a change takes place in an electromagnetic system, that thing happens which tends to oppose the change.* Thus, by way of illustration, if we attempt to thrust a magnet into a coil, Fig. 337, there is developed in the coil, due to the induced current, poles which oppose the motion of the magnet; and likewise if we attempt to withdraw a magnet from a coil, a reverse induced current is produced which in turn gives rise to a magnetic field opposing the motion of the magnet. This all means that whenever we produce any change in the magnetic system, work has to be done in overcoming the opposing forces. Lenz's law has a very wide application in electromagnetics.

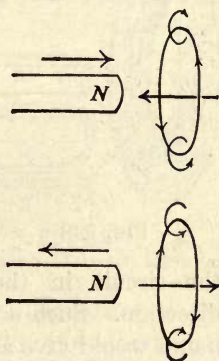


FIG. 337

THE DYNAMO AND ITS USE

380. The Dynamo. One of the most important pieces of electromagnetic apparatus is the dynamo, a machine designed for changing mechanical energy into electrical energy, or for changing electrical energy into mechanical energy. When a dynamo is used for the purpose of transforming mechanical

energy into electrical energy it is called a *generator*; when it is used to transform electrical energy into mechanical energy it is called a *motor*. The fundamental principle governing the operation of the dynamo used as a generator is the production of an induced E.M.F. by the cutting of lines of induction; and when used as a motor, the production of mechanical motion due to the reaction of two magnetic fields.

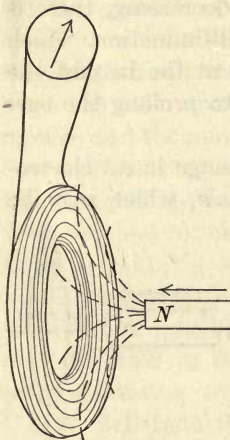


FIG. 338

the circuit in the opposite direction. Such a simple dynamo would give an alternating current; that is, a current flowing at one instant around the circuit in one direction and at the next instant in the opposite direction.

In the commercial dynamo, however, the cutting of the lines of induction may be accomplished not by moving the magnet, but by moving the coil or armature; that is, by the rotation of the armature about its axis in the magnetic field, as shown in Fig. 339. When the armature rotates

381. The Simple Dynamo. Let us consider the dynamo as a generator. One of the simplest forms of generators is that illustrated in Fig. 338. When the magnet is thrust into the coil, lines of induction cut across the wires of the armature and a momentary current flows through the circuit; when the magnet is withdrawn the lines of induction cut across the conductors in the opposite direction and a momentary current flows through

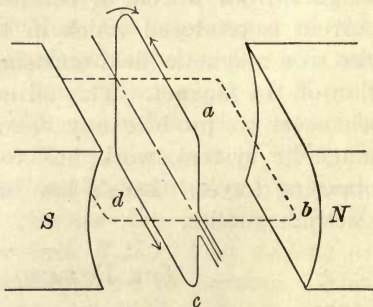


FIG. 339

through the arc abc , that is, makes one half revolution, the cutting of the lines of induction gives rise to an induced E.M.F. as indicated by the arrows; on the second half of the revolution, that is cda , the cutting of the lines of induction is reversed with respect to the conductors and the induced E.M.F. is in the opposite direction. Thus, starting with the armature coil in a vertical position, ac , the current, for the first half revolution, flows around the coil in one direction; for the second half revolution, in the opposite direction. The current in the armature, then, is always an alternating current.

382. Terms Relating to the Dynamo. The magnets represented by N and S , Fig. 340, are called the *field magnets*, and the space between them is called the *magnetic field*. The coil of wire which rotates in this field, is the *armature*. The two metal strips B and B' , which conduct the current from the armature, are the *brushes*. The conductor through which the current flows is the external circuit, or *main line*.

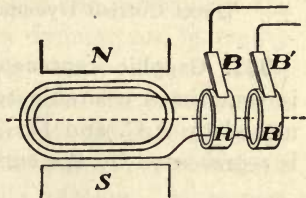


FIG. 340
Alternating Current Dynamo

When the current is conducted from the armature to the brushes by means of separate rings, Fig. 340, one attached to each end of the wire of the armature, the dynamo delivers to the main line an *alternating current*, and is for this reason called an *alternating current dynamo*. The symbol for the term alternating current is A.C., and the diagram which is commonly employed to represent an A.C. dynamo (generator or motor) is shown in Fig. 341.

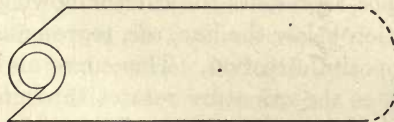


FIG. 341

The symbol for the term alternating current is A.C., and the diagram which is commonly employed to represent an A.C. dynamo (generator or motor) is shown in Fig. 341.

When the current is conveyed to the brushes by metallic segments, c and c' , Fig. 342, which device is called a *commutator*, the dynamo is called a *direct current dynamo*. The

symbol for the term direct current is D.C., and the diagram illustrative of the D.C. dynamo is that of Fig. 343. A graphic representation of an end view of a commutator and brushes is shown in Fig. 344.

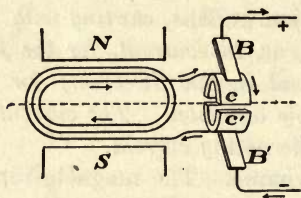


FIG. 342
Direct Current Dynamo

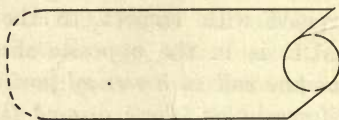


FIG. 343

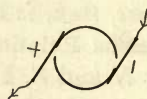


FIG. 344

383. Graphic Representation of an Alternating Current. It is sometimes desirable to represent graphically currents furnished by A.C. and D.C. generators. An alternating current is represented by the curve of Fig. 345, in which that portion

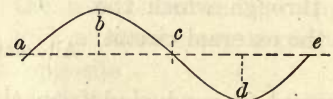


FIG. 345

of the curve above the line, *abc*, represents the current flowing in one direction, and the portion below the line, *cde*, represents the current flowing in the opposite direction. This curve also shows the rise of the current as the armature rotates through the field. When the armature is passing through the position *ac*, Fig. 339, it is cutting a minimum number of lines of induction; hence the current has a minimum value, as represented by the points *a*, *c*, and *e* on the curve. When the armature is passing through the position *bd*, Fig. 339, it is cutting a maximum number of lines of induction; hence the current is a maximum, as represented by the points *b* and *d*.

384. Graphic Representation of a Direct Current. The

curve of Fig. 346 represents what is called a direct current; that is, one which is furnished to the external circuit by the use of a commutator. It will be noted that all the loops of the curve lie on one side of the axis. This means that all the impulses of the current are in the same direction. A direct current as furnished by a generator is not necessarily a continuous current, but rather a series of impulses.

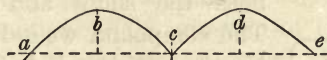


FIG. 346

385. The Magnetic Field of a Dynamo. In general dynamos depend for their magnetic induction upon the principle of the electromagnet. Indeed the poles of a dynamo are in reality nothing more than the poles of a big electromagnet. The manner of exciting this magnet depends upon the use to which the dynamo is put. In the direct current generator there is usually enough residual magnetism in the poles to start at least a small current in the armature upon its rotation. All or part of this current is caused to flow around the field circuit, thus increasing the pole's strength. In this way the dynamo is said to "build up" its magnetic field.

In alternating current dynamos this method of exciting the field cannot be directly employed, since the current in the external circuit is an alternating current. In A.C. generators, therefore, the field is excited from some outside

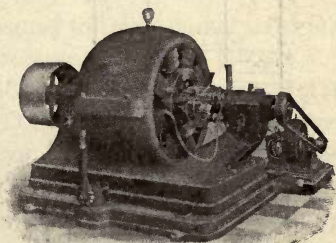


FIG. 347

source, Fig. 347, such as a battery or a small D.C. generator.

386. Kinds of D.C. Generators. With reference to winding the field magnets there are three types of D.C. generators, known as series, shunt, and compound wound.

In the *series wound dynamo*, Fig. 348, all the current of the main circuit passes around the field circuit. In the *shunt wound dynamo*, Fig. 349, only a portion of the current is carried around the field circuit. In the case of the *compound wound dynamo*, Fig. 350, there is a double circuit around the field magnet, consisting of both the shunt and the main line. The compound wound dynamo is very largely employed today where it is desired to furnish a constant E.M.F. at some distant point from the power house.

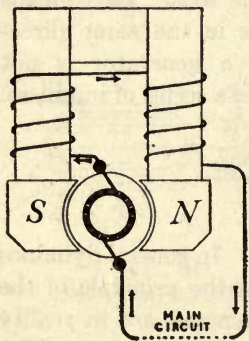


FIG. 348.—Series Dynamo

A discussion of the theory and use of these three types is beyond the limits of an elementary text; suffice it to say that in general the series machine was designed to furnish currents of constant strength; shunt and compound wound machines to furnish currents of constant potential.

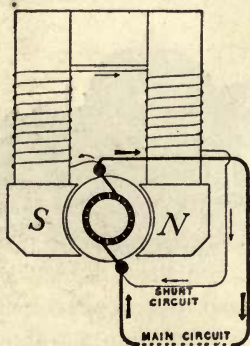


FIG. 349.—Shunt Dynamo

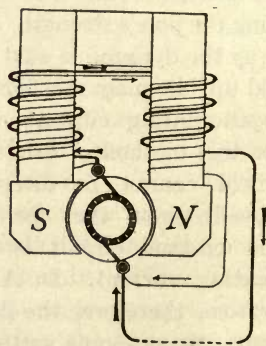


FIG. 350.—Compound Dynao

387. The Alternating Current Dynamo. Generators of the A.C. type are now almost universally used for the purpose of

commercial lighting. The alternating current dynamo differs in principle from the direct current dynamo, as already explained, in only two respects: (a) The armature of the machine is provided with rings instead of a commutator and (b) the field of the A.C. generator has to be excited by some outside source.

388. The Electric Motor. An *electric motor* is a device for transforming the energy of an electric current into the energy of mechanical motion. The principle of the motor does not differ from that of the generator, except that in one case the armature is rotated by mechanical means, thus generating a current; while in the other case a current is forced through the armature, causing it to rotate, due to a distortion of the magnetic field. Any ordinary D.C. generator, if connected up with a source of E.M.F., will operate as a motor; and on the other hand, any D.C. motor may be operated as a generator. For example, if an electric car be allowed to run down grade, its motor may act as a generator.

Motors are of two general types, with respect to the kind of current they are

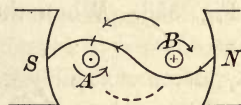


FIG. 351.

designed to take; namely, (a) D.C. motors and (b) A.C. motors.

389. Direct Current Motors.

A D.C. motor, like a D.C. generator, is provided with a commutator. As the current flows through the armature wires, lines of induction appear around each, Fig. 351, thus distorting the magnetic field. A photograph of such

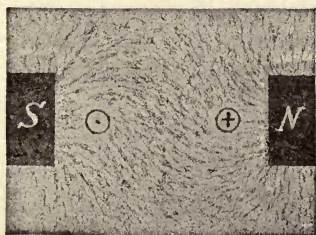


FIG. 352

a distorted field is shown in Fig. 352. A wire was passed through two holes in a glass plate, in at A, then around and out at B. The plate was then placed upon the poles, N and S, of a magnet and iron filings sprinkled upon it. When no

current flowed through the wire AB , the lines of induction passed directly from N to S in straight lines. When, however, a current was passed through the wire, in at the right and out at the left, the lines of induction of the field were distorted. Now the tendency of these distorted magnetic lines is to straighten, thus causing the armature AB to rotate, as shown in Fig. 351.

390. The Back E.M.F. in a Motor. *Experiment.* When the armature of a motor rotates in a magnetic field, as explained in the preceding topic, it cuts some lines of induction and therefore tends to act as a generator. This gives rise to a counter or back E.M.F. in the armature, which opposes the applied E.M.F. at the brushes. The faster a motor rotates, therefore, the greater is the back E.M.F. developed, and hence the less current it takes. This fact may be demonstrated by means of a motor, in the circuit of which there is connected an ammeter, Fig. 353. When the current is turned on, the pointer of the

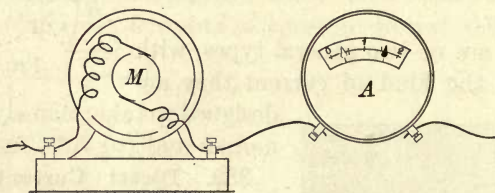


FIG. 353

ammeter gives a large throw, showing that a large current is flowing through it. As the motor speeds up, however, it develops a back E.M.F. which opposes the applied E.M.F. at the brushes thus cutting down the current, as indicated by the fall of the pointer.

It is because of the fact that the current through the armature of a motor depends upon its speed that a "starting box," Fig. 354, is used in connection with motors of any considerable size. A *starting box* is a sort of resistance box so devised as

to enable the operator by throwing a switch to reduce the resistance in the circuit and thus gradually increase the E.M.F. as the motor speeds up. If the full current were turned on while the motor is at rest the chances are that the initial current would be so great that the armature would be burned out. The motor-man on the trolley cars uses a form of starting box which he operates in starting his car.

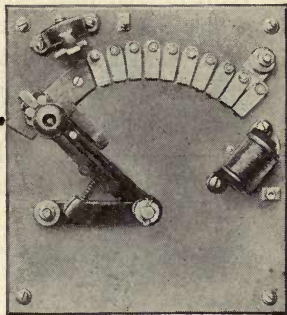


FIG. 354. — Starting Box

391. The Alternating Current Motor. Since alternating currents are very extensively used now for domestic and public lighting, it is not always convenient or possible to make use of the D.C. motor. Alternating current motors are therefore commonly employed. Of the A.C. motors there are a number of different types, the one in most common use being known as the induction motor, a familiar example of which is seen in the small motor used to operate electric fans, sewing machines, vacuum cleaners, and similar household devices.

392. The Transformer. *A transformer is a device for changing a current of high potential to one of low potential, or changing a current of low potential to one of high potential.* The principle may be understood by considering Fig. 355. Suppose that an alternating current flow in the coil marked *P*, called the pri-

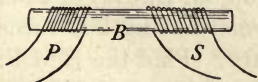


FIG. 355

mary. The effect of this current in the primary will be to magnetize the bar *B*. This will have the same effect as thrusting the magnet into the coil *S*, called the secondary. Let us suppose that the effect on the secondary is the same as if an N-pole had been thrust into it. When the current reverses in the primary the polarity of the magnet is changed; for example, an

N-pole becomes an S-pole. The effect of this change of polarity is the same as if the magnet were withdrawn, reversed with regard to its pole, and again thrust into the coil. Now it will be remembered that thrusting an N-pole into a coil gives rise to a direct E.M.F.; withdrawing the magnet gives rise to an indirect E.M.F. So, too, every time the current flows one way in the primary there is induced an E.M.F. in one direction, and every time the current reverses in the primary there is induced in the secondary an E.M.F. in the opposite direction. An alternating current in the primary produces an alter-

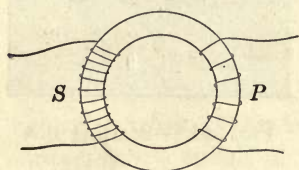


FIG. 356

nating E.M.F. in the secondary, and therefore an alternating current provided the secondary circuit be closed.

In Fig. 356 there is shown a form of transformer of the ring type. A coil of wire *P* is the primary and *S* the secondary. The relation between the E.M.F. of the primary and that of the secondary is determined by the relation of the number of turns of wire in the primary to the number of turns in the secondary. This relation may be expressed as follows:

E.M.F. of P: E.M.F. of S = No. turns primary: No. turns secondary.

Example. An alternating current having an E.M.F. of 2200 volts flows in the primary of a transformer having 200 turns in the primary coil and 10 in the secondary. Find the E.M.F. of the current in the secondary. *Solution:* $2200:x = 200:10$; hence $x = 110$ volts.

This means that by the use of such a transformer as described in this example a high tension current having an E.M.F. of 2200 volts could be "stepped down" to a current having an E.M.F. of 110 volts.

393. The Use of the Transformer. The transformer makes possible the transmission of electrical energy in the form of

high potential alternating currents from a central power plant to points where the energy is to be used. By means of the transformer a current on the high tension wires may always be stepped down to a current of low potential. Small commercial transformers, as shown in Fig. 357, are often attached to electric lighting poles adjacent to dwellings. Their function is of course to step the high potential current down to one of low potential such as is safe to use in the lighting of houses, the running of domestic motors, etc.

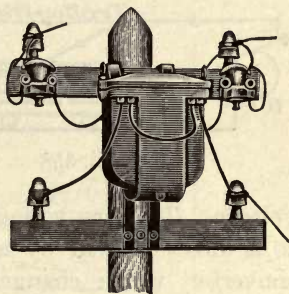


FIG. 357

The reason for using high tension currents on the transmission lines is primarily one of economy in two respects. (a) When a very high E.M.F. is used very little attention has to be paid to the resistance of the line. The effect of high resistance can always be overcome by using a still higher E.M.F. We may therefore use relatively fine wire for the high transmission purposes, its resistance not being an important factor. The use of fine wires means a reduction in the expense of installing the system. (b) There is another reason also why a current of high voltage and low amperage is economical so far as transmission is concerned, and that is the fact that the heat lost for low current transmission is very much less than that for high current, since the heat generated in a conductor is proportional to the square of the current strength. We thus see that in high tension transmission we use wire through which there flows currents of low amperage but of very high voltage. By means of transformers this high voltage current is stepped down to one of low voltage and proportionally high amperage.

394. The Electric Car. An electric railway system in general includes a D.C. generator, a circuit, including the trolley

wires and tracks, and cars provided with D.C. motors, Fig. 358. It is customary to generate the electric power at some central station and then to distribute it to the various sub-stations by means of high tension alternating currents under

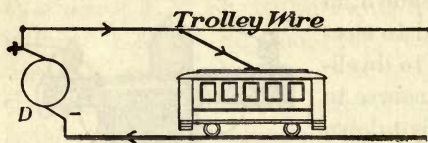


FIG. 358

a pressure, usually of about 23,000 volts. At the transforming station these high tension currents are stepped down by means of transformers to a relatively low

voltage. This low voltage alternating current is then changed to a direct current by means of a device known as a rotary converter, which changes the alternating current from the transformer into a direct current, which is supplied to the trolley wires. The potential between the trolley wire and the track is usually about 650 volts.

ELECTROMAGNETIC APPLIANCES

395. The Electric Bell. The essential parts of an electric bell system are the battery, the push button, and the bell, as shown in Fig. 359. The push button, Fig. 360, is a device for making and breaking the circuit. The parts of an electric bell are shown in outline in Fig. 361. When the circuit is closed by pressing the button the current from the battery magnetizes the iron core of the electromagnet *m*. This attracts the iron strip *a*, causing a break in the circuit at *s*. As the piece of iron moves downward it causes the clapper *c* to strike the bell. The moment the circuit is broken, however, the spring throws the armature *a* back to the point *s*, thus again closing the circuit.

396. The Telegraph. The operation of telegraphing from one point to another by means of the *key* and *sounder* system may be explained in connection with Fig. 362. The current from the battery at station *A* may be traced through the elec-

tromagnet m through the line L , the electromagnet m' , the battery at B , thence through the earth back to A .

Suppose now we wish to telegraph from A to B . The operator first opens his switch s . He now presses down key k ,

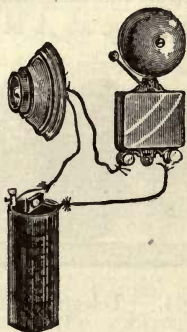
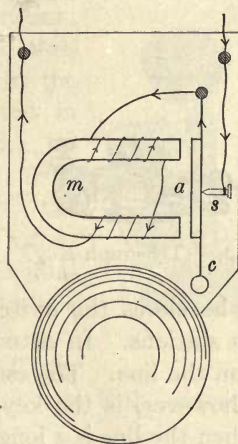


FIG. 359

FIG. 360
Push ButtonFIG. 361
Diagram of Electric Bell

which closes the circuit through the line to B and back through the earth. When the current passes through the two electro-

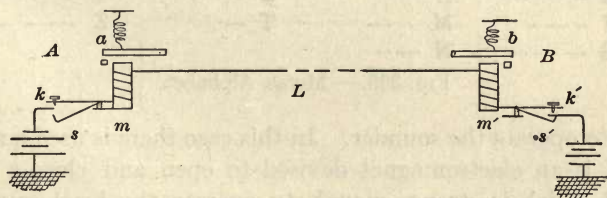


FIG. 362. — Diagram of Simple Telegraph

magnets m and m' , a and b are drawn down, giving rise to the clicking noise characteristic of the telegraph instrument. The

combination of magnet and armature is called a sounder. Every time the key at *A* is pressed down there is produced in the sounder at both *A* and *B* corresponding long or short clicks, called dots and dashes. The operator at *B* reads the dots and dashes as they are sounded upon his instrument, and writes out the message. When the operator at *A* is through



FIG. 363. — Telegraph Key

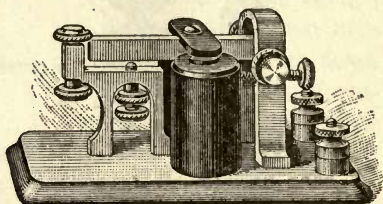


FIG. 364. — Telegraph Sounder

sending, he closes the switch *s*. This diagram above shows only two stations. In actual practice a great many stations may be on the line. The essential pieces of apparatus in each station, however, is the key, Fig. 363, and the sounder, Fig. 364. When the line is a long one, the current is sometimes too

A — —	H — — — —	O — —	U — — —
B — — — —	I — —	P — — — —	V — — — —
C — — —	J — — — —	Q — — — —	W — — — —
D — — —	K — — —	R — — —	X — — — —
E —	L — — —	S — — —	Y — — — —
F — — —	M — — —	T — —	Z — — — —
G — — — —	N — —		

FIG. 365. — Morse Alphabet

weak to operate the sounder. In this case there is used a relay, which is an electromagnet devised to open and close a local circuit which is strong enough to operate the local sounder. (Supplement, 579.)

In Fig. 365 there is shown the Morse code, in which dots and dashes represent letters of the alphabet.

397. The Telephone. The characteristic features of a simple telephone are shown in Fig. 366. The working parts of a telephone system as outlined in Fig. 367 are the *transmitter* T , the *receiver* R , *induction coil* I , *local battery* and the *line* L .

The operation of the system may be briefly explained thus. When a person speaks into the transmitter T , Fig. 367, the metallic diaphragm is set in vibration, pressing against the carbon c , and thus producing a variable resistance in the local circuit. This varying current in the induction coil I produces an induced current in the line which affects the magnet of the receiver R' , the diaphragm of which is set in vibration. It is the vibrations of this diaphragm which produce the characteristic tones of the telephone. When a person speaks into the transmitter T' the same transmission of vibrations occur with respect to the receiver R .



FIG. 366

398. The Induction Coil. An *induction coil* is an apparatus for producing high E.M.F. by the principle of electromagnetic induction. It is really a step-up transformer. The appear-

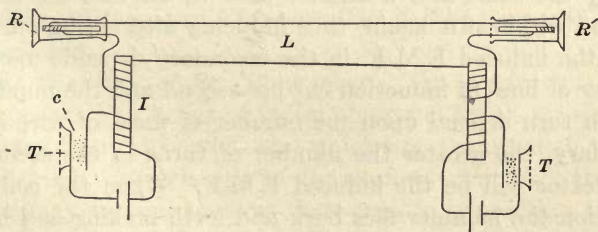


FIG. 367. — Diagram of Simple Telephone

ance of the ordinary coil is shown in Fig. 368; a sectional drawing in Fig. 369. Surrounding the iron core are two coils of wire,

the primary P and the secondary S . The primary coil which is wrapped directly around the core consists of a few turns of heavy insulated wire, which is connected with the battery. The secondary wire consists of many turns of very fine wire, and is not connected in any way with the primary. Underneath the coil is a condenser C which consists of a number of sheets of tin foil carefully insulated from each other.

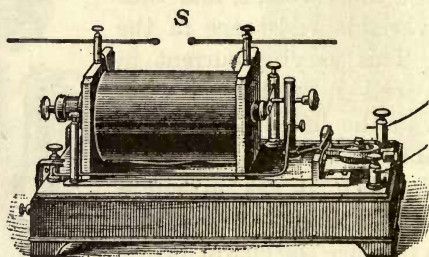


FIG. 368. — Induction Coil

The operation of the coil is as follows: When the key is closed a current flows around the primary circuit, thus magnetizing the core, which in turn attracts the iron a . This breaks the primary circuit exactly as in the case of the electric bell. Now the effect of magnetizing and demagnetizing the core is exactly the same as if a magnet were thrust into the secondary and withdrawn again, thus inducing alternating currents. Since the induced E.M.F. in the secondary depends upon the number of lines of induction cut per second and the number of lines in turn depend upon the number of turns of wire in the secondary, the greater the number of turns in the secondary the greater will be the induced E.M.F. When the coil is in operation the hammer flies back and forth making and breaking the primary circuit, thus magnetizing and demagnetizing the core. This produces an induced E.M.F. in the secondary which manifests itself in the stream of sparks across the terminals of the secondary. The induced E.M.F. of the second-

ary is usually determined by the length of spark which the apparatus will give in dry air between the spherical knobs of the secondary. To produce a spark one centimeter in length between spheres of one centimeter in diameter requires a potential of about 25,000 volts. Induction coils have been made which are capable of giving a spark 50 centimeters in length. To do this would require a difference of potential between the

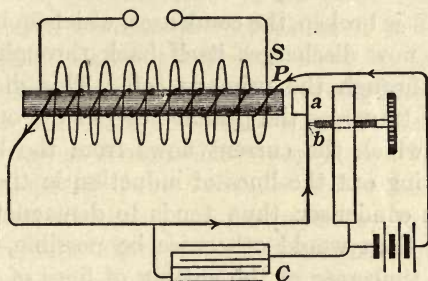


FIG. 369

knobs of the secondary of more than a million volts. It must be borne in mind, in this connection, that the induction coil does not enable us to increase the energy furnished by the primary circuit. While the E.M.F. of the secondary circuit is very high the current is proportionally small. Since the power of a current is equal to EI we see that if E be increased I must be decreased.

399. The Use of the Condenser. The *condenser C*, Fig. 369, consists of a series of layers of tin foil which are carefully insulated from each other and which are connected to the primary circuit on each side of the contact point *b*. The condenser may be said to have three uses in connection with an induction coil, as follows: (a) It prevents sparking at the point *b*. When the current flows around the primary circuit and the hammer *a* is drawn away from the point *b* a spark is produced. The production of a spark at this point is detrimental for two

reasons: it tends to burn off the point, and in the second place it prevents a sudden breaking of the primary current. Now when the condenser is in the primary circuit the energy of the primary current, instead of being expended in the formation of a spark, is expended in charging the condenser, one side becoming positively charged, the other negatively charged.

(b) Now while the hammer *a* is drawn to the magnet and the primary circuit is broken, the condenser, which an instant before was charged, now discharges itself back through the battery and around through the primary coil. This discharge from the condenser traverses the primary coil in the opposite direction to that which the current flows from the battery, thus suddenly cutting out the lines of induction in the core. This action of the condenser thus tends to demagnetize the core more rapidly than would otherwise be possible, and thereby increases the time rate of the cutting of lines of induction by the secondary, thus increasing the induced E.M.F.

(c) The third important function of the condenser grows out of this sudden interruption of the spark at the break. The current at "make" takes a fraction of a second to grow up to its maximum value; while at the "break" by the use of the condenser the cessation is almost instantaneous. Thus the rate of cutting of the magnetic lines of induction is much greater at the "break" than at the "make." The induced E.M.F. at the make lasts longer than at the break, but is feeble and does not suffice to send sparks across the gap. On the other hand, the induced E.M.F. at the break manifests itself by a brilliant torrent of sparks between the terminals of the secondary. Thus we may say that one function of the condenser is to produce a *uni-directional current* between the knobs of the secondary. This is important in certain kinds of experimentation, as, for example, with X-ray tubes.

HIGH POTENTIAL PHENOMENA

400. Experiments with High Tension Currents. By means of an induction coil or other kind of transformer it is possible to step a current up to a very high potential. Now when currents of high potential occur in the form of a spark discharge some very beautiful, interesting, and at the same time highly important results are obtained. A few years ago experiments with high tension currents were considered to be interesting but of little practical value. Today, however, the production of the Roentgen or X-rays, the operation of wireless telegraphy, and similar phenomena are not only of great scientific interest, but also of immense commercial importance.

401. The Geissler Tube. *Geissler* tubes are glass tubes which have been exhausted to a low pressure and sealed. Into the ends of the tubes there are sealed two short pieces of platinum wire which serve as electrodes. When these electrodes are attached to the poles of a static machine or to the terminals of an induction coil the tube becomes brilliantly lighted with colors which vary with the nature of the gas enclosed and with the kind of glass of which the tube is made. When the tube contains a trace of nitrogen the color given on discharge is violet; hydrogen, on the other hand, gives red. These tubes are often drawn into fantastic shapes, Fig. 370, which much enhance the beauty of their color effects.



FIG. 370

Geissler tubes derive their name from *Geissler*, a German physicist (1814–1879), who invented a type of the mercury air pump, which he used in the exhaustion of these tubes. *Geissler* tube effects are obtained when the pressure is reduced to about 0.002 of an atmosphere.

402. The Crookes' Tube. The *Crookes' tube*, named after Sir William Crookes, who was one of the first to work with it,

is a tube from which the air has been thoroughly exhausted. Fig. 371 shows a form of the Crookes' tube much used in physical laboratories at the present time to illustrate the Crookes' tube effects. *A* and *C* are platinum electrodes sealed into the

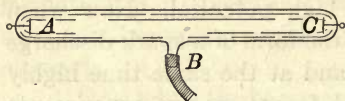


FIG. 371

glass. *B* is a tube leading to the air pump. *A* is connected with the positive pole of the high tension apparatus, *C* to the negative pole; *A*, there-

fore, is the anode and *C* the cathode. Let us suppose, to begin with, that the tube is filled with air. On turning on the current no spark discharge occurs between *A* and *C*. Now if the tube be exhausted, after a time a discharge will occur between the anode and the cathode. First it occurs as a reddish band, and later, as the exhaustion continues, this breaks up and the tube glows with a greenish light. When this occurs the exhaustion has reached the point of about 0.01 mm. of mercury. The tube is now called a Crookes' tube, and a regular discharge takes place between the electrodes. This occurs only when the exhaustion has been carried nearly to the point of a perfect vacuum.

Another familiar form of the Crookes' tube is that shown in Fig. 372.

403. Cathode Rays and Electrons. *Cathode rays are streams of particles called electrons which are shot off from the cathode with great velocity, and which upon striking the inner portions of the tube give rise to the characteristic glow already noted. An electron is a particle having a negative charge of electricity; its velocity is about one-third the velocity of light. If a body positively charged be brought near a stream of electrons they are attracted; if a negative body be presented they are repelled. If a magnet be brought near them as*

FIG. 372
Crookes'
Tube

shown in Fig. 373, the cathode rays are deflected from their course.



FIG. 373. — Cathode Rays deflected by Magnet

404. The X-Ray. *Roentgen* or *X-rays*, as they are sometimes called, were discovered by Roentgen, a German physicist, in 1895. The exact nature of these rays is not yet perfectly understood. Most physicists hold, however, that they are pulses in the ether, propagated with enormous speed through space.

It is important to note that the X-ray is not a cathode ray.

When cathode rays (streams of electrons) fall upon an object, as the metal reflector of a Crookes' tube, Fig. 374, they give rise to X-rays, somewhat analogous to the manner in which a stone dropped into water gives rise to water waves. The cathode ray is no more the X-ray than the

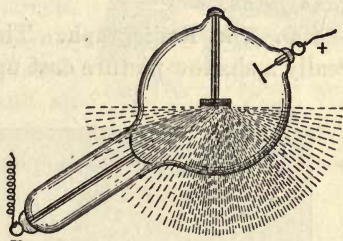


FIG. 374. — X-Rays

stone is the water wave; one is the cause of the other. X-rays do not carry electrical charges and cannot be reflected or refracted as are light waves.

405. Properties of X-Rays. Roentgen rays possess certain remarkable properties which may be stated briefly as follows: (a) Roentgen rays excite phosphorescence in a large number of substances. (b) Gases through which Roentgen rays pass become conductors of electricity. Thus if a charged electroscope be placed in the neighborhood of an active X-ray tube it will be observed that the gold leaves collapse, the charge of the instrument being rapidly carried away by the conduct-

ing air. (c) These rays have great penetrating power, being able to pass through bodies of considerable thickness. Different substances absorb the rays in different degrees, as is well illustrated by the parts of the human body. The bones, for example, absorb the rays more strongly than do the fleshy parts. Metals also absorb the X-rays more strongly than do the non-metals, such as wood or paper. The penetrating power of Roentgen rays is determined largely by the pressure of the gas within the tube. High exhaustion gives rays of high penetrating power, known as "hard rays"; somewhat lower exhaustion gives rays of less penetrating power which are known as "soft rays."

Roentgen rays produce photographic action somewhat similar to that due to light, giving rise to the X-ray photograph or *radiograph*.

406. The Radiograph. The so-called X-ray photograph is really a shadow picture cast upon the photographic plate by the

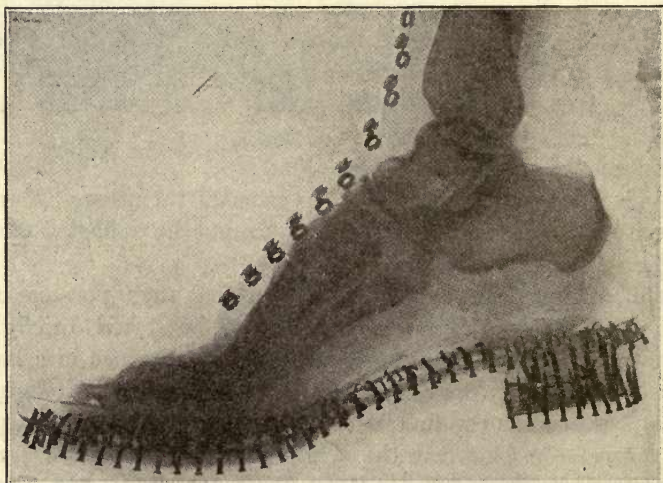


FIG. 375. — Radiograph

body through which the X-rays are passed. The possibility of obtaining these radiographs depends upon the absorbing power of different parts of the body to be photographed. The denser portions of the human body, for example, such as the bones, absorb the rays, thus giving a dark impression upon the picture. In Fig. 375 there is shown a radiograph of a foot enclosed within a heavy shoe, the bones of the foot and the iron nails of the shoe standing out very clearly.

407. The Fluoroscope. A fluoroscope is an apparatus which enables us to study the effects of X-rays without the use of photographic plates. It consists of a box as shown in Fig. 376, the small end of which is so constructed as to fit closely around the eyes. Over the large end is placed a fluorescent screen, made usually of platino-barium-cyanide. If an object, such as the hand, be placed between this screen and an X-ray tube the outlines of the denser portions of the body may be distinctly seen. Sometimes the fluoroscope is used

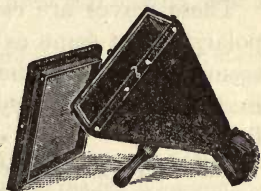


FIG. 376. — Fluoroscope

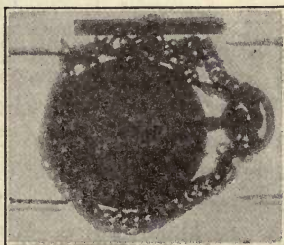
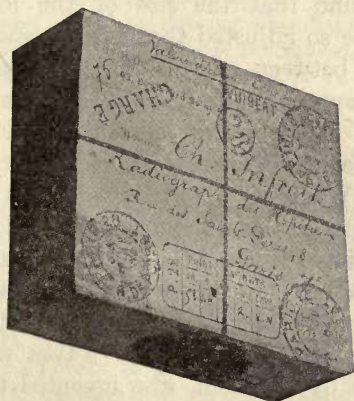


FIG. 377. — Sealed Package and Contents, as revealed by the Fluoroscope

by custom house officers to determine the contents of travelers' baggage. Fig. 377 shows a sealed package and also what the fluoroscope revealed as to the nature of its contents.

408. Electric Waves. In 1887 Hertz (1857–1894), a German physicist, discovered that electrical oscillations, such as occur on the discharge of a Leyden jar, give rise to electrical waves in the ether. Thus when the oscillatory discharge occurs between the knobs of an electric machine or between the terminals of an induction coil, electric waves are set up in the ether and travel out in all directions from the source.

These waves are capable of being reflected, refracted, and polarized the same as light waves; in fact the electric waves seem to possess all the properties of light waves, differing only in the fact that they are very much longer than those of light.

409. The Principle of Wireless Telegraphy. In order to detect waves, Hertz used a device called a spark-gap detector,

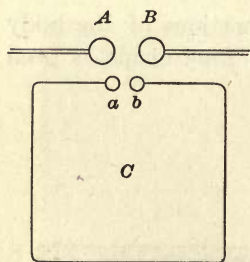


FIG. 378

Fig. 378. This consists of a rectangular wire C set up near the poles of an electric machine or induction coil. It was found that the size of the loop could be so adjusted that when a spark passed between AB a smaller spark would appear at ab . That is to say, electric disturbances started at AB could be made to record their presence at ab . When the loop is in condition to give a spark at the knobs ab , it is said to

be in tune with the discharging system AB . This discovery by Hertz contained the fundamental principle of signaling through space by means of electric waves. The idea of the transmission of messages by means of electrical waves was later developed and perfected by Marconi, who invented the modern wireless system which in recent years has become of such great commercial importance. (Supplement, 580.)

EXERCISES AND PROBLEMS FOR REVIEW

1. What is the distinction between a magnetic substance and a magnet?
2. State the law of magnetic attraction and repulsion.
3. Explain the term "lines of induction." These lines are represented as coming out of which pole of a magnet? Entering which pole?
4. A magnetic needle placed in a magnetic field always tends to set itself in what position with respect to the lines of induction of the field?
5. Make drawings to illustrate magnetic field between (a) like poles; (b) unlike poles.
6. What is magnetic induction? Make drawing to illustrate the induction which occurs in a piece of soft iron when it is brought near a magnet. Indicate the N-pole.
7. Explain magnetic dip. Where with respect to the earth is the angle of dip 90° ?
8. Explain angle of declination. How may this angle be determined for a given place?
9. What is the line of no declination? If a person is east of this line how will the magnetic needle point with reference to the north geographic pole? What is "true north" from a given place?
10. What charge is developed upon glass when it is electrified by rubbing with silk? What charge on sealing wax when rubbed with flannel or cat's fur?
11. A glass rod positively electrified is brought near a spherical conductor. Show by drawing what happens on the conductor. When the charging body (glass rod) is removed, what happens to the two charges on the conductor?
12. Explain how to charge an electroscope (a) by conduction; (b) by induction.
13. Make drawings to illustrate distribution of electricity on (a) a sphere; (b) a pointed body. Explain the action of points in discharging a body. Why does an electrified body when it is covered with dust soon lose its charge?
14. Make drawing of a simple voltaic cell, and in connection with this drawing point out and define (a) positive electrode; (b) negative electrode; (c) electrolyte; (d) external circuit; (e) internal circuit.
15. What is electromotive force? To what is it sometimes likened? Is it a force? In what units is it measured?
16. On what does the electromotive force of a battery depend? What is the relation of the size of a battery (a) to its E.M.F.? (b) to the amount of electrical energy which it can furnish?

17. Define local action, and explain how it may be remedied.
18. Define polarization, and explain how it may be remedied.
19. What is the E.M.F. of (a) a gravity cell? (b) Leclanche cell? (c) dry cell? Which cell would you use on open circuit work, and which on closed circuit work, and why?
20. What is electrolytic dissociation? What is an ion? Write equations to illustrate the dissociation of (a) hydrochloric acid; (b) sulphuric acid; (c) copper sulphate.
21. Explain briefly the decomposition of water by electrolysis. What gas appears at (a) the anode? (b) the cathode? What are the relative volumes of hydrogen and oxygen?
22. State Faraday's law of electrolysis.
23. A current of one ampere will deposit by electrolysis 0.001118 gram of silver in one second. What current will be required to deposit 100 grams of silver in 2 hours?
24. A current of one ampere flows through two electrolytic cells in series, one containing silver nitrate (AgNO_3) and the other copper sulphate (CuSO_4). (a) How much silver will be deposited in 1 hour? (b) How much copper?
25. Make drawing to illustrate the silver coulometer and explain its use in determining current strength.
26. Define: Ampere, ohm, volt, coulomb.
27. A wire which is stretched in a north-south direction carries a current. It is desired to find the direction of the current, and to this end a magnetic needle is placed below the wire. The N-pole of the needle is deflected to the east. Determine by the right hand rule the direction of the current in the wire. On another occasion the needle was placed above the wire, the N-pole being again deflected to the east. Find the direction of the current.
28. Wrap a string around a lead pencil after the manner of a solenoid. Consider the current to flow in a given direction in the string, and determine by the right hand rule the polarity of the point of the pencil.
29. State Ohm's law; write the law in the form of an equation.
30. On what four factors does the resistance of a conductor depend? State the laws of resistance in the form of an equation.
31. Find the resistance of 10 ft. of No. 30 platinum wire, the value for k for platinum being 70 ohms per mil-foot. The diameter of a No. 30 wire is 0.01003 in., that is, 10.03 mils.
32. Find the resistance of 1000 ft. of No. 18 iron wire. To find the value of k for iron, see Art. 350; to find the diameter of No. 18 wire, see Supplement, 611.
33. A conductor consists of three wires connected in series, the resist-

ance of the wires being 10, 20, and 30 ohms respectively. What is the resistance of the conductor?

34. A current of 2 amperes flows through the conductor of problem 33. Find (a) the fall of potential ($E = RI$) over each of the three wires; (b) the fall of potential over the entire conductor.

35. Two wires of 20 and 30 ohms resistance are connected in parallel between the points A and B . Find the resistance of the two wires thus connected.

36. A current flows through the two wires of problem 35, between the points A and B . The portion of the current flowing through the first wire (20 ohms) is 3 amperes; that through the second, 2 amperes. What is the fall of potential over (a) the first wire? (b) the second wire?

37. A current of 11 amperes flows from A to B over a divided circuit consisting of three wires in parallel. The resistance of the wires is 10, 20, and 30 ohms respectively. Find (a) the total resistance between A and B ; (b) the fall of potential between A and B ; (c) the current in each wire.

38. It is desired to find the resistance of a given conductor, AB , by Ohm's law. A current is passed through the conductor. An ammeter placed in the circuit reads 2 amperes. A voltmeter connected to the terminals A and B indicates a fall of potential of 3 volts. Find the resistance between A and B .

39. Five gravity cells, each having an E.M.F. of 1 volt and an internal resistance of 5 ohms, are joined in series. A wire having a resistance of 25 ohms is connected to the terminals of the battery. Find (a) the resistance of the entire circuit; (b) the current flowing in the wire.

40. Suppose that the 5 cells of problem 39 are connected in parallel. What current will flow through the wire?

41. The E.M.F. of a battery is equal to the fall of potential around the entire circuit. A wire having a resistance of 2 ohms is connected to the terminals of a cell having an internal resistance of 1 ohm. The current flowing through the circuit is 0.5 ampere. Find (a) the fall of potential over the external circuit; (b) over the internal circuit; (c) around the entire circuit. What is the E.M.F. of the cell?

42. Three dry cells, each having an E.M.F. of 1.5 volts and an internal resistance of 1 ohm, are connected in series to a conductor having a resistance of 7 ohms. Find (a) the resistance of the entire circuit; (b) the current in the conductor; (c) the fall of potential over the conductor; (d) the fall of potential over the internal circuit; (e) the total fall of potential around the entire circuit. How does this total fall of potential compare with the E.M.F. of the battery?

43. A current of 3 amperes flows for 10 minutes through a wire having

a resistance of 5 ohms. Find the amount of heat generated in the wire in calories.

44. An electric flatiron having a resistance of 22 ohms is connected to a lamp socket which gives an electric pressure of 110 volts. Find (a) the current flowing through the flatiron; (b) the amount of heat in calories generated in 1 hour.

45. Find the power expended in the iron in (a) watts; (b) kilowatts.

46. Find the energy expended in kilowatt hours during a period of 2 hours use. Compute the cost of running this flatiron at the rate at which electrical energy is sold in your town.

47. The lines of induction of a magnetic field are directed from south to north. A conductor lying in an east-west direction falls vertically through the field. Determine by the right hand rule the direction of the induced E.M.F.

48. A single armature loop makes 1 revolution in the magnetic field of a dynamo. Explain by the right hand rule the direction and changes of the induced E.M.F. during this revolution.

49. In a given transformer the number of turns in the primary are to those in the secondary as 10 : 1. Is this a step-up or a step-down transformer? An E.M.F. of 1000 volts applied to the primary will give rise to what E.M.F. in the secondary?

50. Make outline drawing, and explain operation of (a) an electric bell; (b) simple telegraph; (c) telephone; (d) induction coil.

For additional Problems and Exercises, see Supplement, 580.

CHAPTER X

SOUND

SOUND AND WAVE MOTION

410. Definition of Sound. The word sound is used in two distinct senses. From the viewpoint of the physiologist, sound is a sensation; from that of the physicist, *sound is that form of vibratory motion which may be perceived by the ear.* The question is often asked: If a tree were to fall and there were no ear to hear, would there be any sound? In the sense in which the word is used in physiology, there would be no sound; in the sense in which the term is used in physics, there would be sound, because the tree in falling would set up vibrations of the air which would be capable of affecting the ear, if one were present.

Acoustics is that branch of physics which is devoted to the study of sound and its properties.

411. The Origin of Sound. Experiment. All sound originates in vibrating bodies. If a sound be traced to its source, there will always be found a vibrating body. If a tuning fork be set in vibration and then brought in contact with a small glass or ivory ball, Fig. 379, the ball will be thrown vigorously from the fork, due to the vibrations of the latter. Again, if the prongs of a tuning fork be thrust into water the latter will be thrown about in a fine spray. Other illustrations of the fact that sound is generated in vibrating bodies may be seen in the vibration of a guitar string. If the string be plucked aside and released it will give a musical note, and at the same time seem to spread out into a broad band with a hazy outline,



FIG. 379

Fig. 380, which diminishes to the original size of the string as the sound dies away. Also the tremulous motion of a bell may be perceived by placing the hand upon it while it is sounding.

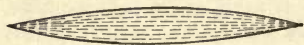


FIG. 380

412. Examples of Vibrations.

It has been stated that all sound originates in vibrating bodies. Now bodies may vibrate in a great many different ways; for example, the branches of a tree or the heads of grain in a field vibrate back and forth in the wind, each part in its motion to and fro traveling through the arc of a circle. Also, a ball suspended as shown in Fig. 381 is an example of a to and fro vibration in which the body during each swing sweeps out the arc of a circle. A chip on the surface of deep water moves up and down when a wave runs under it. If the water be shallow, the chip not only moves up and down, but back and forth as well, its motion being elliptical.

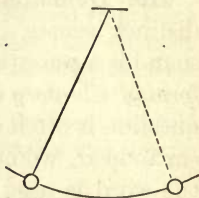
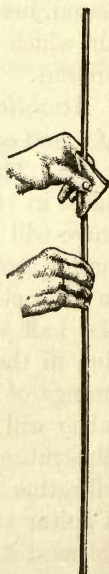


FIG. 381

If a ball attached to a rubber band be pulled downward and then released it will vibrate up and down in a straight line, Fig. 382. A vibration somewhat similar to this occurs when a glass rod is stroked with a damp cloth, as shown in Fig. 383. Grasp the rod in the middle with one hand and with a damp cloth stroke one end lightly. The glass rod will emit a distinct musical note, and at the same time a tremulous motion will be felt by the hand grasping it. Vibrations run from one end of the rod to the other in a manner somewhat analogous to the up and down motion of the ball attached to the rubber band.



FIG. 382



413. Wave Motion. When a disturbance occurs FIG. 383

in an elastic medium, such as air or water, waves are set up. A *wave motion* represents a continuous handing on from particle to particle of a disturbance in a medium without an actual transfer of the medium itself. One of the most familiar



FIG. 384

examples of wave motion is that which occurs on the surface of water. Suppose that a stone be dropped into a lake or a pond, Fig. 384; the waves run out from the point of disturbance in concentric rings. To the observer it would appear that the water is actually being carried forward. This is not true, however, as may be seen by watching the motion of a chip floating upon the surface. As the waves move forward from *A* to *B*, Fig. 385, the motion of the particle upon the surface is up and down, as from *c* to *d*. Another excellent illustration of wave motion is seen in the passage of a wind wave over a field of grain. As the wave runs forward each individual head of grain swings back and forth.

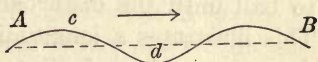


FIG. 385

The distinction between the motion of a particle of the medium and the motion of the wave itself is of fundamental importance. The bobbing up and down of the chip on the surface of the water and the swinging back and forth of the head of grain are both illustrations of the motion of the particle of the medium. In the case of the water the motion of the particle (the chip)

is at right angles to the direction of the motion of the waves; in the case of the grain the motion of the particle (head of grain) is back and forth in the same general direction as the motion of the wave.

414. Kinds of Wave Motion. There are two kinds of wave motion: (a) transverse and (b) longitudinal.

A *transverse wave* is one in which the vibrating particles move at right angles to the direction of the motion of the wave. A good illustration of transverse waves are those seen on the surface of the water; also a series of waves traveling along a rope or string.

A *longitudinal wave* is one in which the vibrating particle moves back and forth in the same direction as the motion of

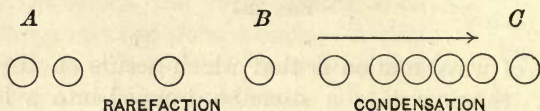


FIG. 386

the wave. Longitudinal waves may also be illustrated by a row of balls suspended as shown in Fig. 386. If a disturbance be set up by striking ball *A*, it will be passed along from ball to ball until the disturbance has run the length of the line. This illustrates a longitudinal wave, which consists of a condensation and rarefaction. As the wave runs forward from *A* to *C* there is a point where the particles are crowded together. This is called a *condensation*. At the point *B* the particles have begun to swing back toward *A*; this portion of the wave is called a *rarefaction*. A condensation and a rarefaction together constitute the entire wave.

415. Relation of the Medium to the Kind of Wave Transmitted. *Substances like solids, which possess rigidity, are capable of transmitting both transverse and longitudinal waves.* For example, if a steel rod clamped in the middle, as shown in Fig. 387, be plucked at one end it will vibrate transversely; that is,

the motion of the rod is at right angles to its length. The same rod may also be made to transmit longitudinal waves. If it be stroked lightly about one-fourth the distance from the end with a soft piece of leather upon which there has been dusted some powdered resin, the rod will give forth a distinct note of high pitch, and a light



FIG. 387

ivory ball suspended at one end will be thrown out vigorously, as shown in Fig. 388. Longitudinal waves consisting of condensations and rarefactions run the length of the rod from one end to the other and back again, as shown by the motion of the ball.

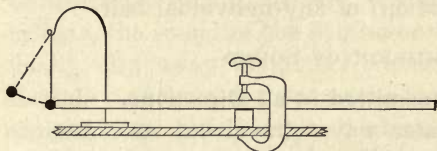


FIG. 388

Substances which do not possess rigidity, such as fluids (air and water, for example), are capable of transmitting only longitudinal waves; that is, waves consisting of condensations and rarefactions. Sound waves in air or in water, then, are transmitted by longitudinal waves. It must be noted here that while a wave in water is an example of a longitudinal wave, a wave on the surface of the water is an example of a transverse wave.

416. Wave Length and Amplitude. *A wave length is the distance measured in a straight line from any point in a given wave to the corresponding point in the next wave. In transverse waves we usually measure the*

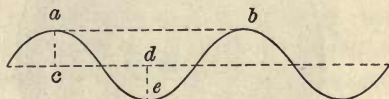


FIG. 389

wave length from crest to crest or from trough to trough, as from a to b, Fig. 389. In longitudinal waves we measure the wave length from condensation to condensation or from rare-

faction to rarefaction. A wave length, however, is not necessarily measured from crest to crest or from condensation to condensation; it may be measured from any point in a wave to the corresponding point in the next wave.

The amplitude of vibration is one-half the distance through which a particle swings as the wave runs under it. In transverse waves the amplitude is measured at right angles to the direction of propagation of the wave, *ac* and *de*, Fig. 389. In longitudinal waves amplitude is measured in the same line as the direction of propagation of the wave. In the case of the swinging balls the amplitude of vibration is one-half of the space swept by the swing (vibration) of any individual ball.

TRANSMISSION OF SOUND

417. Sound Waves Transmitted in all Directions. Just as the transverse surface water waves travel out in concentric circles in all directions over the surface from the point of disturbance, so in a somewhat similar manner sound waves in air travel outward in the form of condensations and rarefactions from the point of disturbance in a series of concentric spherical shells. Suppose, for example, a bell be struck. As it vibrates it sets up a series of condensations and rarefactions which travel outward, as shown in Fig. 390. These waves

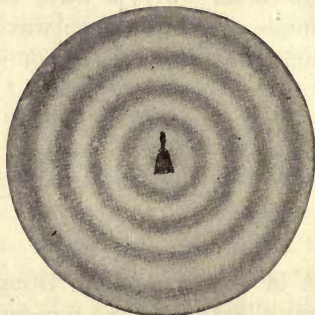


FIG. 390

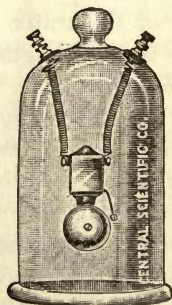


FIG. 391

striking upon the ear produce, due to the change of pressure caused by the condensations and rarefactions, a disturbance in the organs of hearing which give rise to the sensation of hearing.

418. Sound Waves not Transmitted through a Vacuum.

The characteristics of a medium suitable for the transmission of sound waves are as follows: (a) The medium must be elastic, (b) continuous, and (c) ponderable, that is, it must have weight.

Experiment. If an electric bell be placed within a bell jar, Fig. 391, and the circuit be closed, the ringing of the bell can be distinctly heard. If now the air be exhausted from the bell jar, the sound of the bell becomes fainter and fainter, and finally dies away altogether. Sound waves will not travel through a vacuum, for the reason that it has no medium fulfilling the characteristics named above.

419. Velocity of Sound. The velocity of sound in any medium depends upon two factors: (a) the elasticity of the medium and (b) its density. The greater the coefficient of elasticity e of the medium, the greater the velocity; also, the greater the density of the medium d , the less the velocity. The relation of the velocity of sound to these two factors is expressed definitely by the equation

$$\begin{aligned} \text{velocity} &= \sqrt{\text{coefficient of elasticity} / \text{density}} \\ v &= \sqrt{e/d} \end{aligned}$$

Example. If the velocity of sound in a given medium under given conditions of elasticity and density be 1000 feet per second, how will the velocity be affected if the coefficient of elasticity be increased fourfold and the density be increased from 1 to 16? *Solution:* 1000: $v = \sqrt{1/1} : \sqrt{4/16}$; hence $v = 500$ feet per second.

420. Velocity of Sound in Different Media. The velocity of sound in air was first determined by two observers stationing themselves several miles apart. A cannon was fired by one,

and the other observed the flash and counted the number of seconds required for the sound to reach him, it being assumed that the time required for the light to travel from the cannon to the observer was so small as to be negligible. In this way a calculation of the velocity of sound in air was made. Many later experiments have been devised and carried out to determine accurately the velocity of sound in different media.

The velocity of sound in air at 0° C. is 1090 feet, or 332 meters per second.

The velocity of sound in water at 4° C. is 4674 feet per second. That is, *the velocity of sound in water is about four times the velocity of sound in air.*

The velocity of sound in steel is 16,500 feet per second, about *fourteen times the velocity of sound in air.*

The reason the velocity of sound in liquids and solids is greater than that in air is due to the fact that the coefficient of elasticity of liquids and of solids is very many times greater than that of air.

421. Relation of Temperature to Velocity. An increase in temperature causes an increase in the velocity of sound. The reason for this will be made clear when we consider the equation $v = \sqrt{e/d}$. When air, which is free to expand, is heated, its elastic properties remain unchanged while its density is diminished, and thereby the value of v is increased. On the other hand, if the air be confined in a vessel of constant volume and heated, it could not expand, hence there would be no change in the density, but the coefficient of elasticity would be increased, and as a result the value of v would again be increased. Thus we see that a change in temperature causes an increase in the velocity of sound.

An increase in temperature of 1° C. causes an increase in velocity of sound in air of (a) 2 feet, or (b) 0.6 meter per second.

422. Reflection of Sound. When sound waves strike against an obstructing medium, such as the face of a cliff, the wall of a building, the trees of a forest, or even against the vapors of a

cloud, they are reflected; that is, they bound off, as does a ball when thrown against a wall. Sound waves reflected from a smooth concave surface may be brought to a focus by a similar concave surface as shown in Fig. 392. The ticking of a watch placed at *a* may be distinctly heard at *b*, although it may be entirely inaudible

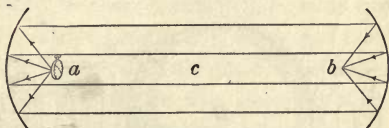


FIG. 392

at *c*, midway between the two. The reflection of the sound is illustrated in the use of the speaking tube and in the case of the echo.

423. The Echo. If a person call at a distance from a reflecting medium, in a very short time his voice will be returned to him in an echo. The echo is due to the fact that the sound waves traveling outward strike against the medium and are reflected back to the source. The echo is never as loud as the original sound because a portion of the energy of the wave is always lost by absorption at the reflecting surface and a small portion is also lost in traveling from the person to the reflecting medium and back again. Since the sensation of sound lasts for one-tenth of a second, it follows that in order to hear an echo of one's voice it is necessary to stand far enough away from the reflected surface so that more than one-tenth of a second will elapse between the origin of the sound and its return. Since sound travels at the rate of about 1100 feet per second, it would therefore be necessary to stand at a distance greater than 55 feet from the reflecting surface in order to hear the echo.

424. Refraction of Sound. Sound waves may be refracted. (Refraction is the change of direction of the motion of a wave due to its passage from a medium of one density to a medium of different density.) For example, if a series of sound waves originating at the point *A*, Fig. 393, strike against the balloon shaped body *B*, containing carbon dioxide, which is more

dense than air, the waves will be bent in such a way that the sound will come to a focus at *C*. This may be readily understood when we consider what will happen to the portion of the

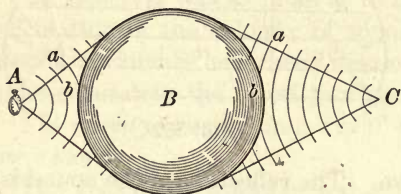


FIG. 393

wave marked *ab*. Since *b* gets into the dense medium first, its speed is retarded, hence the line of direction is bent downward, as shown; *a* gets out of the medium first, and hence travels with a greater speed than *b*, thus

bending the wave further towards *C*. Of course when both portions of the wave get into the air they travel with the same velocity. If the balloon shaped vessel were filled with a gas lighter than air, such as hydrogen, the waves, instead of converging and coming to a focus as shown, would diverge.

LOUDNESS AND INTENSITY OF SOUND

425. Loudness of Sound. The loudness, or intensity of sound, depends upon four factors: (a) the amplitude of vibration, (b) the distance of the sounding body from the ear, (c) the density of the medium, and (d) the area of the sounding body. The distinction between intensity and loudness lies in this: Intensity depends upon the energy of the vibrating particle; loudness depends not only upon the energy of the vibration, but also upon the nature of the hearing apparatus, the ear. Thus two persons may hear a sound of given intensity with a different degree of loudness. For a given ear a change in intensity produces a change in the loudness with which the sound is heard; a change in loudness, on the other hand, does not necessarily imply a change in intensity, since loudness depends both upon the intensity and upon the nature and condition of the hearing apparatus.

426. Relation of Intensity to Amplitude of Vibration. *Experiment.* If, for example, the prongs of a tuning fork be tapped lightly so that they vibrate through a very small arc, a faint sound is heard; if now they be struck sharply, so that the prongs vibrate through a very much larger arc, they give off a sound much louder than the first. It can thus be shown that *the intensity of sound varies directly as the square of the amplitude of the vibrating body.* If a vibrating body having an amplitude of one unit produce a sound of given intensity, then if the body be made to vibrate through an amplitude of two units, the intensity will be four times as great.

427. Relation of Intensity to Distance. *Intensity varies inversely as the square of the distance.* It is a common experience that if we walk away from a sounding body the loudness decreases as the distance increases. It can be demonstrated both experimentally and mathematically that the intensity varies inversely as the square of the distance from the source. Consider that a cannon be fired at *C*, Fig. 394. We

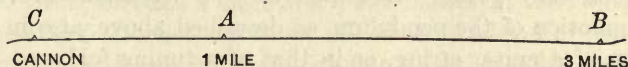


FIG. 394

wish to compare the intensity of the sound at *A*, distant one mile from *C*, with the intensity of the sound at *B*, distant three miles. Since intensity varies inversely as the square of the distance, the intensity at *A* will be nine times as great as at *B*; that is, $I : I' = 3^2 : 1^2$.

428. Intensity Depends upon the Density of the Medium. *The denser the medium the louder the sound; the rarer the medium, the less loud the sound.* As one ascends in a balloon, the air becomes rarer and rarer as the distance from the earth increases and the loudness of the sound, therefore, diminishes. If, on the other hand, a person were to go into a deep mine or down in a diving bell, the sound of the human voice would

be much louder than at the surface of the earth, due to the increase in density.

429. Relation of Intensity to Area. *Intensity depends upon the area of the vibrating body.* *Experiment.* If a tuning fork be set in vibration and held in one hand, a sound of a given loudness will be heard. Now if the tuning fork, while still in vibration, be placed in contact with the top of the desk or upon a resonance box, the sound will at once become very much louder, due to the fact that a body of increased area is set in vibration.

RESONANCE AND INTERFERENCE

430. Free Vibrations. The vibration of a pendulum free from all influences, except that due to the attraction of gravity, is an example of a *free vibration*. If there were no friction, the pendulum would continue to vibrate forever. As it is, however, all freely vibrating bodies sooner or later come to rest, due to the damping effect of the friction of the medium in which they swing. Examples of free vibrations are seen in the motion of the pendulum, as described above, also in the motion of a guitar string, or in that of a tuning fork.

431. Force Vibrations. When a body vibrates not in response to its own nature but in response to some periodic force applied to it, we have what is called a *forced vibration*. A good illustration of a forced vibration is that of the motion of the pendulum of a clock or the balance wheel of a watch, in which case the vibrating bodies move in response to a periodic force applied to the weights or spring. Other examples of forced vibrations are those of the sounding board of a piano, or the body of a violin, or the case of the desk when the stem of the tuning fork is pressed upon it.

432. Resonance. When the period of the vibrating body is the same as that of the impressed force we have a special case of forced vibration known as *resonance*. If, for example, two tuning forks of the same period be mounted near to each

other, Fig. 395, and one set in vibration and after a few moments stopped, it may be observed that the other fork is vibrating, as may be demonstrated by a light ivory ball suspended so as just to touch the fork. This is due to the fact that the impulses of the air from the first fork act upon the second, and since its period of vibration is the same as that of the impulses impressed upon it, it responds. A further illustration of the relation of the impressed force to the period of the vibrating system is seen in the case of the swing.

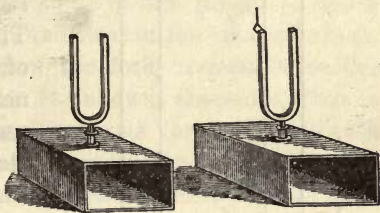


FIG..395

A little child may set a heavy swing in vibration, provided the impulses (pushes) be so timed as to coincide with the period of vibration of the swing. First the swing moves through a very small arc, but soon it responds to the periodic impulses, and may after a time swing through a large arc. The motion of the swing is an example of a forced vibration, and since its period of vibration coincides with the impulses imparted by the child, we have a case of resonance.

A striking illustration of resonance is that of the vibration of a bridge, due to the footfalls of a small dog running across it. If the period of the impulses imparted by the dog agree with the period of the bridge, the latter will be set in vibration. Soldiers when crossing a bridge are commanded to break step, to avoid the possibility of doing damage to the structure, due to the resonance in response to the regular steps.

433. Resonators. *Experiment.* A tube so adjusted that the air within it vibrates in unison with some outside vibrating body, such as a tuning fork, is called a *resonator*. If a glass tube, Fig. 396, be partly immersed in water and moved up and down while a fork vibrates about it, there will be found a certain point at which the tube will respond to the fork; that

is, the resonance tube will give out a relatively loud sound. Now if a fork having a different vibration rate be held above the tube, no response is heard. If, however, the tube be moved

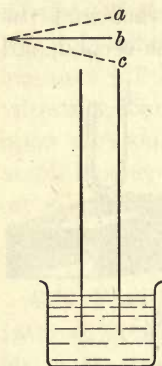


FIG. 396



FIG. 397

up or down, there will be found another point at which it will respond to the second fork. Thus each fork requires a tube of a certain length to be in resonance with it. This illustrates resonance in the case of a tube closed at one end, as by the water. Resonance for a given fork may also be obtained from a tube open at both ends, provided the tube be twice the length of the closed tube, Fig. 397.

434. Explanation of Resonance in a Tube. Let a , b , c represent the motion of one prong of a tuning fork which is

vibrating at the mouth of a closed resonance tube, so adjusted as to respond to the fork. As the prong of the fork moves from a to b a condensation is sent down into the tube. While the fork moves from b to c and comes to rest for a moment in changing its direction of motion, the condensation has time to run down the tube, strike the water, be reflected, and get back to c in time to join the new condensation which is formed as the fork moves from c toward b . The condensations and rarefactions which are reflected from the bottom of the tube coincide with the condensations and rarefactions of the sound waves given off by the fork, thus producing a reinforcement of the sound, and hence giving rise to an increase in loudness.

435. Relation of the Length of a Wave to Length of Resonance Tube. Let us consider again the case of a resonance

tube which is closed at one end and which is responding to a given fork. A sound wave travels one wave length while the fork makes one complete vibration. Now we have learned that during one complete vibration of the fork a condensation travels twice the length of the tube (down and back), and a rarefaction likewise travels twice the length of the tube. A sound wave consists of a condensation and rarefaction each of which, during one complete vibration of the fork, travels twice the length of the resonance tube. It follows, therefore, that a *closed resonance tube* sounding its lowest note is *one-fourth the wave length of the corresponding sound wave in air*.

It may be shown in a somewhat similar manner that an *open resonance tube* sounding its lowest note is *one-half the wave length of the corresponding wave length in air*.

436. Relation of Wave Length to Velocity and Number of Vibrations. Suppose that the fork is making 256 vibrations per second and we desire to find the wave length of the corresponding sound waves in air when the temperature is 20° C. Now the velocity of sound at 20° C. is 1130 feet per second. While the fork is making 256 vibrations sound travels a distance of 1130 feet. This means that in a space of 1130 feet there are 256 waves. Therefore, the length of one wave = $\frac{1130}{256} = 4.4$ feet. It follows then that the length of a wave in an elastic medium is represented by the equation

$$\text{wave length} = \frac{\text{velocity}}{\text{number of vibrations}}$$

$$l = v/n$$

in which l is the wave length, v the velocity of the sound in air, and n the frequency, that is, the number of vibrations per second.

437. How to Measure Wave Length and Number of Vibrations by Means of a Resonance Tube. It is possible by means of a resonance tube to measure with a reasonable degree of accuracy the wave length of the sound given off by a tuning

fork, and also to determine the number of vibrations of the fork, that is, its frequency. Suppose that we wish to determine the wave length and the number of vibrations per second of a given tuning fork. A glass tube one end of which is thrust into water, as already explained, serves as a resonance tube. The given fork is set in vibration and held above the tube, which is moved up and down until the point of resonance is reached. We now measure the distance from the fork to the water, which represents the length of the closed resonance tube. Four times this length equals the wave length of the corresponding sound in air.

Now by means of the relation, $l = v/n$, we may at once determine n , the number of vibrations per second. Suppose the temperature at which the experiment is carried out is 26°C . and that the length of the resonance tube is 10.5 inches. At a temperature of 26°C . the velocity of sound, v , in air $= 1090 + (2 \times 26) = 1142$ feet per second; and wave length $l = 4 \times 10.5$ inches $= 42$ inches $= 3.5$ feet. Now using the equation above, we may write

$$n = \frac{1142}{3.5} = 326 \text{ vibrations per second}$$

Example. A closed resonance tube 18 inches in length responds to a given fork, the temperature of the air being 20°C . Find the vibration rate of the fork. *Solution:* Wave length, $l = 4 \times 1.5 = 6$ feet; velocity of sound, v , at 20°C . $= 1090 + 40 = 1130$ feet per second. Then from the equation $l = v/n$ we may write $n = 1130/6 = 188.3$ feet per second.

EXERCISES. 1. A resonance tube 1 ft. in length responds to a fork making 288 vibrations per second. Find (a) the velocity of sound corresponding to the conditions of the experiment; (b) the temperature.

2. Find the length of a closed pipe that will respond to a fork making 256 vibrations when the temperature is 10°C .

3. Determine the pitch of a fork that is in resonance with a closed tube 15 in. in length at 0°C .

438. Reinforcement and Interference of Sound. If two sound waves occur together so that the condensations and rarefactions of one coincide with the condensations and rarefactions of the other, the resulting sound will be louder than either of the sounds producing it. In Fig. 398 is shown in a

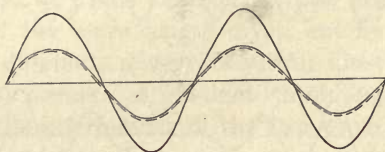


FIG. 398

graphic way the result of adding two sound waves, as has just been described. The resultant sound wave is represented by the line having an amplitude greater than either of the other waves.

On the other hand, if two sound waves be superimposed one upon the other, so that the condensation of one coincides with the rarefaction of the other, the result will be a diminution in loudness. Indeed it is possible for two sound waves to be so impressed one upon the other that silence will result. This condition is shown in Fig. 399, in which is represented graphically



FIG. 399

two sound waves of the same wave length and amplitude, the condensations of one coinciding exactly with the rarefactions of the other. The resultant is represented by the straight line, which indicates silence.

The amplitude of the resultant sound wave is at every point equal to the algebraic sum of the amplitudes of the original sound waves producing it.

439. Beats. Suppose that we have two sound waves of different lengths traveling in the same direction, as shown in Fig. 400. At the points *A* and *C* the waves coincide in such

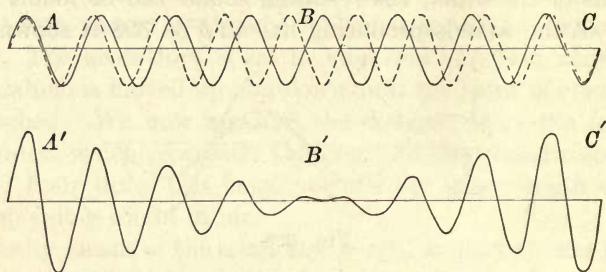


FIG. 400

a way that they reinforce each other. At *B* they interfere in such a way as partially to annul each other. The resultant

wave is represented by the line *A'B'C'*. At the points *A'* and *C'* the sound will be loud; at the point *B'* it will be faint, thus producing a rise and fall in loudness. This periodic increase and decrease in loudness due to the interference of two sound waves is called *beats*.

440. Illustration of Beats.

Experiment. A striking illustration of beats occurs in connection with the singing flame. Let two jets of flame be prepared as shown in Fig.

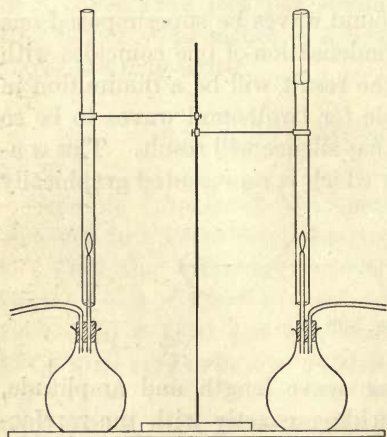


FIG. 401

401. First, over one of the flames place a glass tube about 2 feet in length and from three-quarters to an inch in diameter. Move the tube up and down until a certain position is found

in which the flame will sing, due to the sympathetic vibrations set up in the tube by the fluttering of the flame. Now over the second flame place a second tube *B*, having around one end a cylinder of paper which may be moved up or down as the case may require. The paper slider may be adjusted until the point is reached at which the second tube produces a singing noise. Now if the wave length given out by the two tubes be somewhat different, a very beautiful illustration of interference (beats) occurs. A distinct throbbing sound will be heard due to the interference of the two wave trains.

The *number of beats* which occur per second is equal to the difference in frequency of the two sounding bodies.

PITCH AND MUSIC

441. Pitch. The pitch of a sound depends upon the number of vibrations of the sounding body. When the number of vibrations per second is great, the pitch is high; when small, the pitch is low. If two sounds are produced by the same number of vibrations per second, they are said to have the same pitch, and if sounded together they are said to be in unison.

442 The Siren. Experiment. The *siren* is an instrument for illustrating and determining pitch. It consists of a circular disc having several rows of holes, as shown in Fig. 402, mounted so as to be rotated at some given speed. Now let air be blown against the disc through a tube. When one of the holes of the rotating disc comes in front of the tube, a puff of air goes through, thus producing a condensation; at the next instant the stream of air is shut off by the disc, which produces something corresponding to a rarefaction. Now if the disc be rotated at a given speed, and the tube through which the



FIG. 402.—Siren

air is blown be slowly moved from the center of the disc outward, a series of sounds will be produced which increase in pitch, due to the fact that the number of holes increase from center to circumference. To determine the pitch of any sound, as given by the siren, we would have to know the number of holes in the particular series in front of the tube, and also the number of revolutions of the disc per second. For example, suppose that in the outside row there are 48 holes and the disc is making 10 revolutions per second. This will give $10 \times 48 = 480$ condensations and rarefactions; that is, 480 vibrations per second.

443. The Use of the Siren. If a siren be provided with an apparatus that will count automatically the number of revolutions per second, it is possible by means of this instrument to determine the number of vibrations of a given sound, provided the operator is able to tell by ear when the two sounds, that of the siren and that of the given body, are in unison. Suppose for illustration we wish to determine the number of vibrations made by the wings of a bee buzzing on the window pane. The siren is rotated until the pitch of the instrument coincides with that of the wings of the insect. At this instant the number of revolutions per second is noted, which multiplied into the number of holes passing before the tube gives the number of vibrations per second required. In a similar manner the number of vibrations of any instrument, such as a tuning fork, may be determined.

444. Musical Sounds. *Musical sounds* are those which have a definite pitch and which produce a pleasing effect upon the ear. A *noise* is a combination of sounds in which the ear is unable to detect a definite pitch, as in the confusion of sounds arising from street traffic or in the clatter of machinery in a factory.

The *essential features of music* lie in the elements (a) definiteness of pitch, (b) periodicity, (c) agreeableness to the ear. A series of sounds may be periodic and have a definite pitch

and yet not be pleasing to the ear, as in the case of the beating of the tom-tom in an oriental temple, or in the monotonous cries which accompany an Indian war dance. Occidental or western music differs from oriental music mainly in the character of the sounds which are selected as being pleasing to the ear.

445. Some Musical Terms. (a) A *note*, as used in a musical sense, may refer to a sound having a definite pitch or to a symbol in an arbitrary scale. The word *tone* is often used in the same sense as the word *note*, referring to a sound of a definite pitch; or, on the other hand, it may refer to the sound resulting from a number of notes.

(b) A *musical interval* is the ratio of the pitch (vibration number) of a given note to the pitch of another note. For example, the interval expressed by the ratio 1:1 is called *unison*; that expressed by the ratio 2:1, an *octave*. Thus if one note have a pitch due to 256 vibrations per second, and another 512 vibrations per second, we say that the pitch of the second is an octave higher than the first.

(c) When any three notes having a ratio 4:5:6 are sounded together they produce a tone which is pleasing to the ear; the same is true also of the ratios 10:12:15. A *major chord* consists of four notes having a ratio 4:5:6:8, represented in music as *do, mi, sol, do'*. In Fig. 403 there is shown a set of four forks which sounding together give a major chord. A *minor chord* consists of four notes having the ratios 10:12:15:20. From the major and minor chords we derive our musical scales.

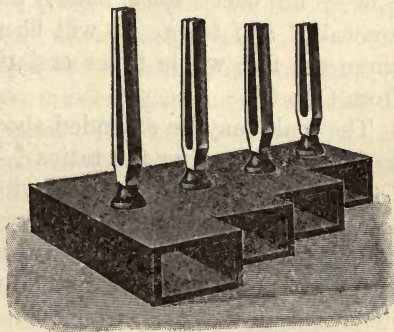


FIG. 403

446. The Diatonic Scale. *The diatonic scale, or gamut, as it is sometimes called, consists of a series of eight notes having definite ratios. The gamut derived from the major chord, based upon the ratios 4 : 5 : 6, is called the major diatonic scale; that based on the minor chord is called the minor diatonic scale. Below is given the major diatonic scale in the key of C, Fig. 404.*

								
Name	DO	RE	MI	FA	SOL	LA	TI	DO
Letter	C	D	E	F	G	A	B	C'
Ratio	1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2
Interval		$\frac{9}{8}$	$\frac{10}{9}$	$\frac{16}{15}$	$\frac{9}{8}$	$\frac{10}{9}$	$\frac{9}{8}$	$\frac{16}{15}$

FIG. 404. — Diatonic Scale

Intervals between two consecutive notes having the ratios of $\frac{9}{8}$ or $\frac{10}{9}$ are called *whole tones*; intervals having the ratios $\frac{16}{15}$ are called *half tones*. It will be noted that in the above scale there are five whole tones and two half tones in the octave from C to C'.

The scale may be extended above or below the octave given in Fig. 404 by using the ratios $\frac{9}{8}$, $\frac{5}{4}$, $\frac{4}{3}$, etc. An octave above C', that is, C'', will have 1024 vibrations; an octave below C, 128 vibrations.

The minor diatonic scale consists of eight notes similar in letter and name to those of the major scale, but having ratios derived from the minor chord.

447. Key Notes. The *key note* is the note taken as *do*, or 1, of the scale. A scale having C as the key note, as written above, is sometimes called the natural scale. In order to accommodate different voices and instruments, however, it is

frequently desirable to change the key note of the scale from *C* to some other note, as for example, *D*, *F*, or *G*. In order to write the scale in any key, all that is necessary is to select the vibration number corresponding to that letter and multiply it successively by the fractions $\frac{9}{8}$, $\frac{5}{4}$, $\frac{4}{3}$, $\frac{3}{2}$, $\frac{5}{3}$, $\frac{15}{8}$, 2, and so on. For example, suppose that we wish to write the scale in the key of *D*. We select *D* from the diatonic scale as our key note, its vibration number being 288. To get *E* we multiply 288 by $\frac{9}{8} = 320$; in a similar manner $F = 288 \times \frac{5}{4} = 360$; $G = 288 \times \frac{4}{3} = 384$; $A = 288 \times \frac{3}{2} = 432$; $B = 288 \times \frac{5}{3} = 480$; $C' = 288 \times \frac{15}{8} = 540$; $D' = 288 \times 2 = 576$. Now having C' we may obtain *C*; that is, $C = \frac{1}{2}$ of $540 = 270$.

Below we have written for comparison scales in the key of *C*, *D*, and *G*.

	<i>C</i>	<i>D</i>	<i>E</i>	<i>F</i>	<i>G</i>	<i>A</i>	<i>B</i>	<i>C'</i>
Key of <i>C</i>	256	288	320	341	384	426	480	512
Key of <i>D</i>	270	288	324	360	384	432	480	540
Key of <i>G</i>	256	288	320	360	384	432	480	512

448. Standards of Pitch. *In physics we assign to middle C 256 vibrations per second. In music, however, the standard of pitch commonly employed is that which assigns to A 435 vibrations per second. This is called the international standard of pitch and is that to which most musical instruments are tuned.*

449. An Octave on the Piano. The keys representing an octave on the piano are shown in Fig. 405, there being eight white and five black keys. The black keys represent notes called sharps and flats. A *sharp* is a note having a vibration number higher than that of a given note; a *flat* is a note having a vibration number lower than the given note. Thus, the first black key above *C* is the sharp of *C* and the flat of *D*. These thirteen notes, eight white and five black, constitute an octave.



FIG. 405

In order to produce music in different keys on instruments having fixed keyboards, such as the piano and organ, it is necessary to determine upon some arbitrary ratio from note to note. This changing the ratios of the diatonic scale to those of other values is called *tempering*. In fixing the ratios from note to note on the piano, musicians have agreed to adopt a system known as *equal temperament*; that is, the ratio between all notes is equal. The ratio number selected as being most satisfactory is the twelfth root of 2; that is, 1.05946. Thus if we fix the value of A as that of standard pitch, namely, 435 vibrations per second, then the sharp of A , the next black key above it, will be $435 \times 1.05946 = 460.9$; the next key, B , will be $460.9 \times 1.05946 = 488.3$, and so on.

450. Tempered Scale of Piano. The vibration numbers for the thirteen notes on a piano, from C to C' , based on A as 435, are given in the following table. The notes marked x_1, x_2, x_3, x_4 , and x_5 represent the five black keys of the octave. $C = 258.7$, $x_1 = 274.1$, $D = 290.3$, $x_2 = 307.6$, $E = 325.9$, $F = 345.3$, $x_3 = 365.8$, $G = 387.6$, $x_4 = 410.6$, $A = 435$, $x_5 = 460.9$, $B = 488.3$, $C' = 517.4$. A tempered scale such as that of the piano is sometimes called a *chromatic scale*.

451. Quality of Sound. Sounds may differ in three respects; namely, (a) in loudness, (b) in pitch, (c) in quality. What we mean by quality or timbre may be illustrated as follows: If middle C , for example, be simultaneously struck on a piano, a violin, and a cornet, the pitch is the same in all three cases; and this may likewise be true of the loudness of the three sounds. We would have no hesitation, however, in assigning one sound to the piano as its source, another to the violin, and the third to the cornet. This property which enables us to assign a musical sound to a definite source is called *quality* or *timbre*. The quality of a musical sound is due to the number and character of the overtones present (Art. 453) and is determined by the form of the resulting sound wave.

VIBRATION OF STRINGS

452. Segmental Vibration of Strings. *Experiment.* • (a) If one end of a long flexible rope be fastened to the wall and the other end moved up and down by the hand in such a way that the rope is caused to swing as a whole, in somewhat the same manner as when used by children in “skipping rope,” we will have an example of a string vibrating in a single segment, Fig.

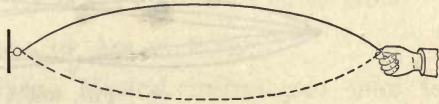


FIG. 406

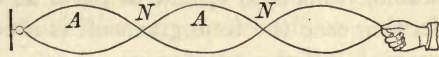


FIG. 407

406. The rope does not vibrate in a vertical plane, but has a somewhat circular motion; this is true, also, of all vibrating strings. If now the hand be moved more rapidly, the rope may be made to break up into two, three, or more segments, as shown in Fig. 407, depending upon the rate at which the impulses are imparted. The points of least motion, *N* and *N*, are called *nodes*; the points of greatest motion, *A*, are called *antinodes*.

453. Fundamental and Overtone. Fig. 408 *A* illustrates a string vibrating in a single segment. In this condition it gives off its lowest tone. The *fundamental* of any sounding body is the tone of lowest pitch which the body is capable of giving.

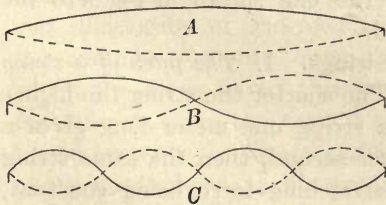


FIG. 408

Fig. 408 *B* illustrates the string vibrating in two segments. In this case it gives off its first overtone, that is, a tone an octave above the fundamental; in *C* the string is represented as vibrating in four segments, giving off a tone

two octaves above the fundamental. An overtone is the tone given off by the sounding body when vibrating in parts.

A string may vibrate as a whole or it may break up into segments, as shown above. Indeed a string may vibrate as a

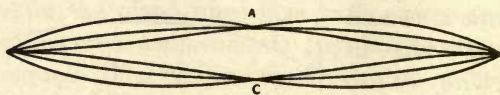


FIG. 409

whole, from *a* to *c*, and in parts at the same time, Fig. 409. In this case the tone given off is a combination of the fundamental and the overtones.

454. The Sonometer. The sonometer is an instrument used in studying the laws of vibration of strings. It is a hollow wooden box upon which is stretched a number of strings. A spring balance or other device is used to determine the stretching force acting on the string (Supplement, 581), while a small

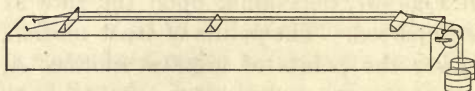


FIG. 410

wooden "bridge" is employed to vary its length. By means of an instrument similar to the one shown in Fig. 410 the following laws may be verified.

455. Laws of Vibration of Strings. I. *The pitch of a string varies inversely as its length.* The shorter the string the higher the pitch. For example, if a string one meter long gives a pitch due to 100 vibrations per second, then the same string half a meter in length, the stretching force being constant, will give a pitch an octave higher than the first; that is, a pitch due to 200 vibrations per second.

II. *The pitch of a string varies directly as the square root of the stretching force.* If a string stretched by a force of one kilo-

gram make 100 vibrations per second, then the same string stretched by a force of 4 kilograms will make 200 vibrations per second; that is, $100:200 = \sqrt{1}:\sqrt{4}$.

III. *The pitch of a string varies inversely as the square root of the mass per unit of length.* Thus for a given length and stretching force, the lighter the string the higher will be its pitch.

VIBRATION OF AIR IN PIPES

456. Vibration in Pipes. Musical instruments may be divided into two great classes: (a) stringed instruments and (b) wind instruments. The notes which are produced by wind instruments are due to the vibration of air columns within them. We commonly speak of a wind instrument as a pipe.

The various kinds of wind instruments differ chiefly in the mode of excitation of vibration of the enclosed column of air. The part of the instrument in which the vibrations are excited is called the mouthpiece. Mouthpieces are of three types: (a) Those in which the air is blown across a sharp edge or across an opening, as in the flute or organ pipe. This form of excitation may be illustrated by blowing across the mouth of a small bottle, or better still, a discharged cartridge shell. A common tin whistle illustrates fairly well the principle of construction of the organ pipe. (b) Those in which the air is forced through an opening which is partly closed by an elastic tongue or reed, as in the cabinet organ, the accordion, etc. An excellent illustration of the reed instrument is that furnished by the common "mouth organ," or harmonica. (c) Those in which the air is forced through a slit, formed by two elastic membranes, as in the case of the vibration of the air as it is forced between the lips in playing the cornet, or the vibration of the vocal chords in the production of voice.

457. Open and Closed Pipes. An *open pipe* is one that is open or free at both ends. In Fig. 411 there is shown an open organ pipe; at one end there is an open mouthpiece, at the other an open or free passage.

In Fig. 412 we have a *closed organ pipe*. There is at one end an open mouthpiece, similar to that of the open pipe; the other end, however, is closed.

In Fig. 413 there is shown a set of four open organ pipes, which when sounding their fundamentals produce a major chord; that is, they sound the notes *do*, *mi*, *sol*, *do'*.

458. Laws of Pipes.

I. *The pitch of a pipe varies inversely as its length;*

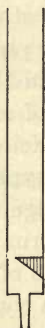


FIG. 411

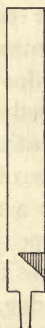


FIG. 412



FIG. 413



FIG. 414

that is, the shorter the pipe the higher the pitch. Experiment. The relation of the length of a pipe to its pitch may be strikingly demonstrated by using a pipe into one end of which is fitted a movable piston, Fig. 414. If the piston be placed at the upper end, and a steady stream of air be blown into the mouthpiece, a tone having a definite pitch will result. If now the plunger be moved downward the pitch will rise, becoming very shrill as the plunger approaches the mouthpiece. By a single downward and upward motion of the piston, the pitch may be made to rise and fall, illustrating the rise and fall of the pitch of a siren whistle.

II. *An open pipe gives a pitch an octave higher than that of*

a closed pipe of the same length. Experiment. Remove the plunger from the pipe used in the preceding experiment. We now have an open pipe of a given length. By blowing gently into the mouthpiece, the pipe will give forth its lowest or fundamental tone. If the hand be now placed over the lower end of the pipe, thus converting it into a closed pipe, it will give forth a tone one octave lower than that given by the open pipe, provided the fundamental in each case is produced.

459. Overtones in Pipes. *Experiment.* If we blow gently upon a pipe, it will give forth its fundamental tone. If now we blow more vigorously the pipe will give a tone an octave higher, that is, will sound its first overtone; blowing still harder, it is possible to make the pipe sound other and higher overtones.

An open pipe is capable of giving a complete series of overtones, having frequencies 2, 3, 4, 5, etc., times that of the fundamental.

A closed pipe is capable of giving only those overtones whose frequencies are 3, 5, 7, etc., times that of the fundamental.

460. Nodes and Antinodes in Pipes. We have learned that a pipe may be made to give forth not only its fundamental tone but also a series of overtones. What happens in the pipe in the case of the production of overtones is somewhat analogous to that which occurs in a string when it breaks up into segments and gives off its overtones. The air column within the pipe may be made to break up into segments forming nodes and antinodes.

We have said that a node in a pipe is somewhat similar to that in a string. *A node in a pipe, however, differs from a node in a string in one very important particular. A node in a string is a point of least motion. A node in a pipe is a point of least motion and of greatest changes of pressure.* (Supplement, 582.)

When an open pipe is sounding its fundamental there is a node at the middle and an antinode at each end, Fig. 415.

There is always an antinode at the open end of a pipe when it is sounding a note.

When a closed pipe is sounding its fundamental there is a node at the closed end and an antinode at the open end, Fig.

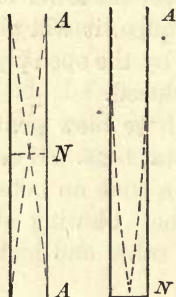


FIG. 415 FIG. 416

416. In a closed pipe there is always a node at the closed end, that is, a point of least disturbance of the air, and an antinode at the open end, whether the pipe be sounding its fundamental or one of its overtones.

The presence of nodes in pipes may be determined experimentally by lowering into the pipe a small paper disc upon which has been placed a few grains of fine sand, Fig.

417. When the disc reaches a node (point of least disturbance) the sand is undisturbed; when the disc reaches an antinode (point of greatest disturbance) the sand is violently agitated.

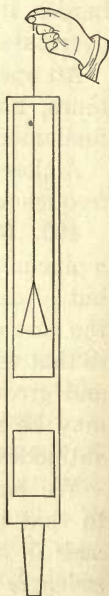


FIG. 417

ORGANS OF VOICE AND HEARING

461. The Vocal Organs. In the upper portion of the throat is a hard projecting mass commonly called "Adam's apple," which constitutes a part of the *larynx*, a box-like chamber formed of cartilages. The larynx is the primary organ of speech and song, and is of all musical instruments the most wonderful, both on account of its simplicity as well as for its extreme delicacy of range. Across the upper end of the larynx there are stretched two muscular membranes, called the *vocal chords*. In Fig. 418 the vocal chords, *cc*, are shown as they would appear if we were looking down upon them. Between the edges of the vocal chords

there is an opening called the *glottis*. When the air is forced through the glottis, the vocal chords are thrown into vibration, which gives rise to the tones characteristic of the human voice. The vocal chords are controlled by muscles. When the edges of the chords are brought close together, that is, when the glottis is small, the vibration rate is high, hence the pitch of the voice is high; when the glottis is large the vibration rate is low, hence the tone is low. A longitudinal section of the larynx is shown in Fig. 419,

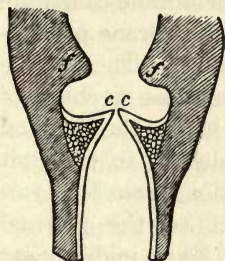


FIG. 419
Section of Larynx

cc representing the vocal chords. Just above the true vocal chords are two folds of mucous membrane, *ff*, called the false vocal chords.

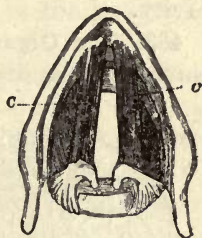


FIG. 418.
Vocal Chords

462. Range and Quality of the Human Voice. The vibration range of the ordinary piano is a trifle over seven octaves, the lowest note being that of about 27 vibrations per second, the highest somewhat above 4000, which is four octaves

above middle *C*. The range of the human voice is, for the ordinary individual, about two octaves. The trained voice of the singer frequently has a range somewhat above two octaves. The lowest note which a bass voice can reach is about two octaves below middle *C*, or about 64 vibrations per second. The highest note which a soprano voice can reach is about two octaves above middle *C*; that is, about 1040 vibrations per second. The pitch of a woman's voice is, in general, about twice as high as that of a man's voice. It must be noted, however, that the range of each is practically the same; namely, about two octaves.

The quality of the human voice is modified by the resonance cavities of the mouth and the nasal passage. If the nostrils

be closed by the fingers and we attempt to recite the words "The moon is beaming," we will have strikingly illustrated the effects of changing the resonant properties of the nasal cavity.

463. The Organs of Hearing. The human ear consists of three parts or divisions: (a) the external ear, (b) the middle

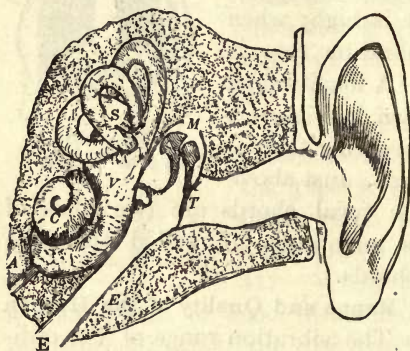


FIG. 420. — Mechanism of the Ear

ear, and (c) the internal ear, Fig. 420. The external ear includes the concha and the tube or canal terminating in a thin membrane called the drum membrane or tympanum *T*. The middle ear contains a chain of little bones, the function of which is to transmit vibrations from the tympanum to the internal ear. The middle ear

communicates with the mouth chamber by means of a tube called the Eustachian tube *E*, the function of which is to equalize the pressure between the air in the middle ear and that on the outside. The internal ear is placed deep in the skull and consists of three parts: (a) the vestibule *V*, (b) the semicircular canals *S*, three in number, and (c) the cochlea, or snail shell *C*, all of which are filled with a watery fluid. In this watery fluid of the internal ear we find the nerve fibers, which spread out from the auditory nerve.

464. How we Hear. The process of hearing begins with the transmission of sound waves to the drum of the ear. These vibrations, it will be remembered, consist of condensations and rarefactions which produce upon the drum membrane changes of pressure, causing it to vibrate back and forth. The vibrations are then transmitted by the ossicles of the middle ear

to the fluids of the internal ear, whence it is transmitted to the fibers of the auditory nerve. This disturbance of the end organs of the auditory nerve produces a nervous impulse which travels to the brain and there gives rise to the sensation of hearing.

465. Limits of Audibility. The human ear is capable of hearing sounds covering a range of about ten octaves. The limits of audibility vary in a marked degree for different individuals. Some exceptional ears can probably hear as high as 40,000 or 50,000 vibrations per second. The ordinary limits, however, lie between 30 and 30,000 vibrations per second. This means that there is a large range of vibration the pitch of which is either too low or too high to be heard.

466. The Phonograph. The phonograph is closely allied to the organs of human speech and hearing so far as simplicity of construction and perfection of execution are concerned. This instrument consists of a mouthpiece across one end of which there is stretched a vibrating disc, to the center of which is attached a needle. This part of the apparatus resembles somewhat the external ear and the tympanic membrane. The needle attached to the disc corresponds somewhat in its working to the bones connecting the drum of the ear with the internal ear. When it is desired to prepare a record the mouthpiece is adjusted so that the needle, communicating with the center of the disc, rests lightly upon a cylinder of some soft substance, such as wax. A person speaking or singing into the instrument causes the disc to vibrate, which in turn causes the needle to trace out in the soft wax, which is in motion, a series of tiny pits or holes of irregular depth. Now if the wax be allowed to harden and the cylinder be moved uniformly under the needle, the latter will vibrate in unison with the irregular depressions contained in its surface. This motion of the needle causes a vibration of the disc in the mouthpiece or horn of the instrument, which in turn sets the air in vibration, producing the characteristic tones of the phonograph.

The quality of tone given by a phonograph depends upon the nature of the needle used, that is, whether it be of metal or wood, and upon the resonating quality of the framework of the instrument.

EXERCISES AND PROBLEMS FOR REVIEW

1. Define: Sound, acoustics, transverse wave, longitudinal wave.
2. Make drawing to illustrate wave length and amplitude in (a) transverse wave; (b) longitudinal wave.
3. Compare the motion of the wave with the motion of the vibrating particle in the case of (a) a surface water wave; (b) a wave passing over a field of grain.
4. Explain the meaning of the following equation, and define each term, $v = \sqrt{e/d}$.
5. Why does the timer in a 200 yard dash start his stop watch by the flash of the pistol rather than by its report?
6. Explain why an increase in temperature causes an increase in the velocity of sound in air.
7. What is the velocity of sound in air, in feet, at (a) $0^{\circ}\text{C}.$? (b) $-20^{\circ}\text{C}.$? (c) $+20^{\circ}\text{C}.$?
8. What is the approximate relation of the velocity of sound in air, water, iron?
9. Explain why the velocity of sound in metals is greater than that in air.
10. A flash of lightning is seen and 5 seconds later the thunder is heard. How far away is the lightning discharge, the temperature being $25^{\circ}\text{C}.$?
11. A sunset gun was fired at exactly 6.30 P.M. at a fort. What time was it when the sound was heard 20 miles away, the temperature being $20^{\circ}\text{C}.$?
12. What is the distinction between loudness and intensity? Upon what four factors does the intensity of sound depend?
13. Explain why striking a bell a vigorous blow causes it to give off a louder sound than if it be tapped lightly.
14. Compare the intensity of a given sound at two points, one a half mile from the source, the other three miles from the source.
15. Explain resonance and give an example.
16. Give the meaning of the following equation, and explain how it is derived, $l = v/n$.
17. A closed resonance tube 2 ft. in length responds to a given fork when the temperature is $25^{\circ}\text{C}.$ Find the frequency of the fork.

18. A closed resonance tube 18 in. in length responds to a fork which makes 320 vibrations. Find the temperature.

19. A closed organ pipe is 3 ft. long. (a) What is the wave length of its fundamental tone? (b) How long must an open pipe be to give the same tone?

20. Define and give illustration of beats.

21. Make drawing to illustrate the effect of two sound waves upon each other such that they produce (a) a louder sound; (b) silence; (c) beats.

22. Define pitch, and explain how a siren may be used to determine the pitch of a sounding body.

23. A current of air was blown against the disc of a siren having a row of 30 holes, while the disc was making 200 revolutions per second. (a) What was the pitch of the resulting tone? (b) If the speed of the siren were doubled, how would the pitch be effected?

24. A whistle in sounding makes a certain number of vibrations per second, which strike the ear of a person who is standing still. Suppose now that the person walk toward the whistle. Will the number of vibrations falling upon his ear per second be increased or diminished? How will it effect the pitch? How do you account for the rise of the pitch of a locomotive whistle which is rapidly approaching?

25. Define: Music, musical interval, octave, major triad, major chord.

26. The tones of three forks form a major triad. The middle fork gives a note of 330 vibrations per second. Find the vibration rate of the other two forks.

27. Define diatonic scale. Name in order the eight notes of which it is composed.

28. How many notes per octave are there in the chromatic scale of the piano? What do the black keys represent?

29. What is the ratio from one key to the next on the piano? What name is given to a system of tempering in which the ratios are all equal?

30. Which offers the greater possibilities to the musician, (a) the piano or the violin? (b) the cornet or the trombone? Give reasons for your answers.

31. Make drawing to illustrate nodes and antinodes in the case of the vibration of strings.

32. Define fundamental tone, overtone. When a string vibrates both as a whole and in parts at the same time, what can you say of the character of the tone given off?

33. In what three ways may sounds differ? Define and illustrate quality of sound.

34. State the laws of vibration of strings.

35. How will the pitch of a string be affected (a) if its length be doubled? (b) if its tension be quadrupled? (c) if the mass be increased nine times?

36. A given string acted upon by a force of 1 lb. makes 200 vibrations per second. What will be the frequency of the string if the stretching force be increased to 4 lbs.?

37. In playing the violin the musician moves the fingers of his left hand back and forth along the string. Explain what effect this has on the pitch.

38. What is the relation of the length of a pipe to its pitch? What is the relation of the pitch of an open pipe to that of a closed pipe? An open pipe of given length is sounding its fundamental. Suppose that a person stop one end by means of a card. How will the pitch be affected?

39. Define node in a pipe, and tell wherein it differs from a node in a string.

40. How may the presence of nodes in pipes be determined experimentally?

41. When a closed pipe is emitting a note what always occurs at (a) the closed end? (b) the open end?

42. Make drawing to illustrate the position of the node within (a) an open pipe; (b) a closed pipe, when each is sounding its fundamental.

43. Make sketch and describe briefly the vocal organs. Explain the condition of the chords when the pitch of the voice is (a) high; (b) low.

44. Make sketch of the ear, and describe how changes of pressure due to condensations and rarefactions of sound waves are transmitted from the external to the internal ear. Describe the Eustachian tube, and explain briefly its function.

For additional Exercises and Problems, see Supplement, 583 and 584.

CHAPTER XI

LIGHT

NATURE OF LIGHT

467. Definitions. A *luminous body* is one which emits light. The sun and the stars are luminous bodies; so, too, is a candle flame or the glowing filament of an incandescent lamp. Bodies which shine by light other than their own are called *illuminated bodies*. The moon is a good illustration of an illuminated body.

A *transparent body* is one which allows light to pass through it readily; that is, it is one which we can see through, as, for example, window glass. A *translucent body* is one which allows only a part of the light to pass through, without permitting objects to be distinctly seen, as in the case of "frosted" glass. An *opaque body* is one which does not allow light to pass through it. It must be noted in this connection that the terms transparent, translucent, and opaque are used in a purely relative sense. Wood, for example, is opaque, yet a shaving from a pine board may be obtained so thin as to be almost transparent. Gold may be beaten out into sheets so thin as to be translucent.

Optics is that branch of physics which treats of light.

468. The Sun a Source of Energy. The sun is not only the most familiar source of light, but it is also the earth's chief source of energy. All the energy of plant and animal life is directly traceable to the sun, as is also the energy furnished by wind and water power. The energy of our coal fields, too, is nothing more than the stored-up energy of the sun's rays of by-gone ages. Now the sun is some 93,000,000 miles from the earth, and the question may be asked: How does this energy

get to the earth across the enormous gulf of intervening space? Two theories have been advanced to explain the transmission of the sun's energy; namely, (a) the emission theory and (b) the wave theory.

The *emission or corpuscular theory*, which was advocated by Sir Isaac Newton, assumed that the energy of the sun is carried through space by tiny particles or corpuscles which are shot off from that body with an enormous velocity, and which carry energy somewhat as a bullet carries energy from a gun. This theory is no longer held by scientific men.

The *undulatory or wave theory*, which was first definitely stated by Huygens, a Dutch physicist, in 1678, and which is now generally accepted, assumes that the energy of the sun is transmitted through space by means of waves, through a medium called the ether.

469. The Ether. The ether is supposed to be a medium which fills all space, not only between the heavenly bodies, but also between the molecules of matter itself, and which is capable of transmitting energy. It seems to offer no resistance to the passage of bodies through it, since in all the centuries in which astronomers have been making accurate observations of the heavenly bodies no retardation has ever been observed. No one has even seen the ether or felt it or weighed it; nevertheless it is convenient to assume that such a medium does exist in order to explain the phenomena of light, radiant energy, and electricity. (Supplement, 598.)

470. The Wave Theory of Light. This theory, to repeat, assumes that the energy of the sun and other luminous bodies is transmitted through space by means of waves. Now only a part of the energy that comes to us from the sun in the form of ether waves appears as light; indeed, ether waves from the sun may be divided into three classes: (a) long ether waves which give rise to heat, and which are sometimes known as "radiant heat"; (b) short ether waves which are known as light waves; and (c) very short ether waves which give rise

to chemical reactions, such, for example, as those which affect a photographic plate. Only those waves which affect the eye are called light waves.

Light may be defined as that vibration of the ether which is capable of affecting the organs of sight.

471. Comparison of Light Waves with Sound Waves. Light waves differ from sound waves in several very important particulars: (a) Sound waves occur in matter; light waves in ether. (b) Sound waves in fluids are longitudinal; light waves are always transverse. (c) Sound cannot be transmitted through a vacuum; light is readily transmitted through a vacuum. (d) Sound waves are comparatively long, the wave length corresponding to middle *C* being about 130 centimeters; light waves are very short, that of yellow light being about 0.0000589 centimeter. (e) The speed of sound waves is insignificant as compared with that of light. It has been found that light waves travel with a velocity nearly a million times as great as that of sound waves in air.

472. Ray, Beam, and Pencil. Since light is transmitted by means of waves its propagation through space may be represented by means of a series of concentric circles, as shown in Fig. 421, in which *L* is the source of light, the waves traveling outward in all directions. The line *LA* shows the direction of motion of a given set of wave fronts and is called a *ray*. A ray is a line drawn to represent the direction of propagation of a wave of light. A *beam* of light is a number of parallel rays, Fig. 422. A *pencil*

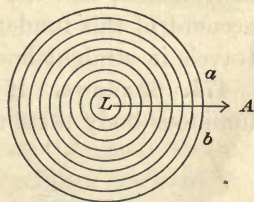


FIG. 421

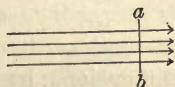


FIG. 422

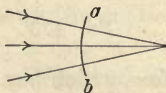
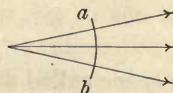


FIG. 423



of light is a number of rays passing through a common point called the focus. Fig. 423 illustrates convergent and divergent pencils. The wave front is represented in each case by the line *ab*.

473. Propagation of Light. *Light travels in straight lines, provided the medium through which it is propagated is homogeneous, that is, a medium having the same density and elasticity throughout.* The fact that light is propagated in straight

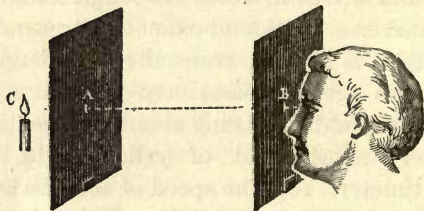


FIG. 424

lines is seen when a beam is passed into a darkened room in which there are particles of dust floating in the air. The marksman in sighting his gun, the surveyor in adjusting his instruments, and the mechanic in much of his work, all take account of this fundamental property of light; namely, that it travels in straight lines, Fig. 424.

474. Shadows. If an opaque object be held in front of a luminous body there appears in the rear of the opaque body a

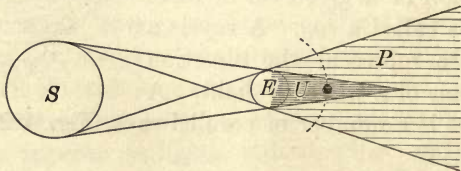


FIG. 425

dark space called a *shadow*, which has three dimensions: length, breadth, and thickness. That portion which appears on the

wall or screen is called a section of the shadow. A shadow may consist of two parts, the *umbra* and the *penumbra*. Fig. 425 shows the umbra and penumbra of the shadow cast by the earth. In an eclipse of the moon this body passes through the cone of the earth's shadow, entering the penumbra first and leaving it last.

475. The Velocity of Light. For a long time it was thought that light was transmitted through space instantaneously. In 1675 however, Roemer, a young Danish astronomer, who was making observations at the observatory at Paris, determined the velocity of light from a study of the satellites or moons of Jupiter. This planet has several moons which revolve about it as our moon does about the earth. The inner one of these satellites passes into the shadow cast by Jupiter, Fig. 426; that is, it is eclipsed once on an average every 42 hours, 28 minutes, 36 seconds. Roemer calculated in advance the exact time that each

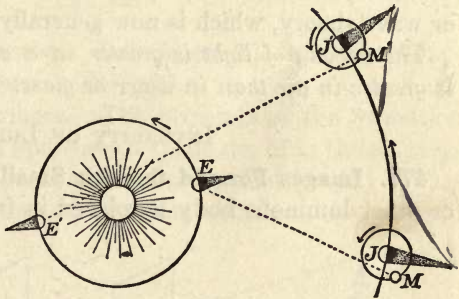


FIG. 426

eclipse should occur for a number of positions of the earth in its orbit. He took a series of observations as the earth moved from *E* away from Jupiter and found the eclipses occurred at regularly increasing intervals later than those which he had computed. When the earth had reached the point *E'*, directly across its orbit from Jupiter, the eclipse occurred about 1000 seconds later than the computed time. He concluded that this apparent delay in the time of the eclipse was due to the time required for light to travel across the earth's orbit a distance of about 186,000,000 miles. Now $186,000,000/1000 = 186,000$: that is to say, the velocity of light is 186,000 miles per second.

Roemer's wonderful discovery was received with but little favor by scientific men, and indeed was practically disregarded for over fifty years until other methods were discovered for measuring the velocity of light.

476. The Velocity of Light in Different Media. According to Newton's corpuscular theory, light should travel faster in a dense medium, such as water or glass, than in a rare medium; according to the wave theory, on the other hand, light should have the greater velocity in a rare medium. Therefore, when in 1850 Foucault, a French physicist, measured, by means of a rotating mirror, the velocity of light in air and in water, and found thereby that the speed of light is greater in air than in water, he thus established on a firm basis the undulatory or wave theory, which is now generally accepted.

The velocity of light is greater in a vacuum than in air, and is greater in air than in water or glass.

INTENSITY OF LIGHT

477. Images Formed through Small Apertures. If a candle or other luminous body be placed in front of a small aperture

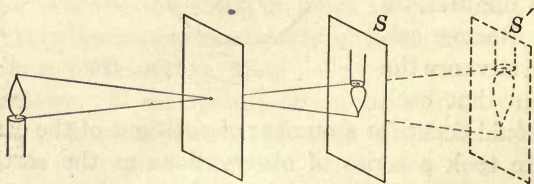


FIG. 427

in an opaque screen, Fig. 427, there will be formed upon a second screen *S* an inverted image of the body. The following points with respect to the formation of images through apertures are to be noted: (a) The image is inverted and perverted; that is, it is upside down with respect to the object and the right side of the image corresponds to the left side of the object. This is due to the fact that rays of light from the

different points of the object pictured on the screen cross as they pass through the aperture. (b) The size of the image depends on the distance of the screen from the aperture. (c) The smaller the opening the less the illumination of the image but the greater the distinctness of outline; on the other hand, as the aperture becomes larger the illumination of the image

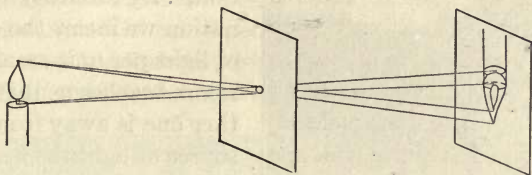


FIG. 428

increases but its distinctness diminishes, due to the overlapping of the rays, as shown in Fig. 428.

478. The Pinhole Camera. The principle of the formation of images through small apertures is made use of in the employment of the so-called pinhole camera in photography. This apparatus consists of a small box painted black on the inside to

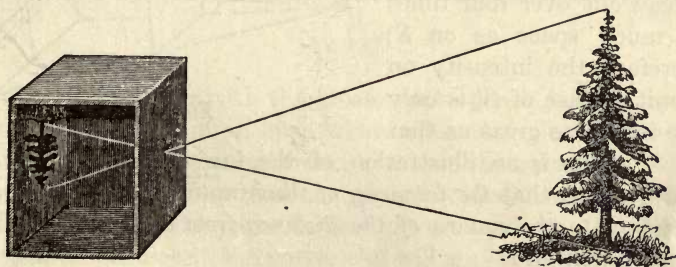


FIG. 429. — Pinhole Camera

prevent undue reflection of the light which is admitted through a small aperture or "pinhole." The photographic film is placed in the rear of the box in such a way as to receive the image of the object outside, as illustrated in Fig. 429. A camera

of this type is very inexpensive and may be employed in photographing landscapes and other scenes where long exposures may be secured. In Fig. 430 there is shown a picture taken by such a camera.

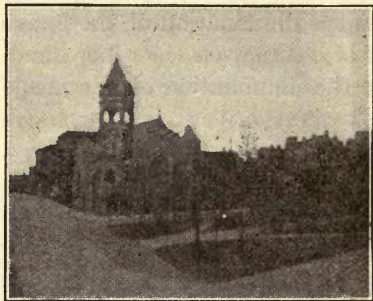


FIG. 430. — This Picture taken by means of Pinhole Camera

479. Intensity of Illumination. By intensity of illumination we mean the quantity of light per unit area. Experience teaches us that the farther one is away from a given source of light the less intense the light becomes. This is due to the divergence of the rays, as shown in Fig. 431.

Consider screen S to be one foot from L and screen S' to be two feet from the source of light. Now the quantity of light which falls upon each screen is the same. The rays falling on S' , however, are spread out over four times as much space as on S ; therefore the intensity on a unit surface of S' is only one-fourth as great as that on S . This is an illustration of the law of inverse squares, which states that *the intensity of illumination is inversely proportional to the square of the distance from the source*. This may be written

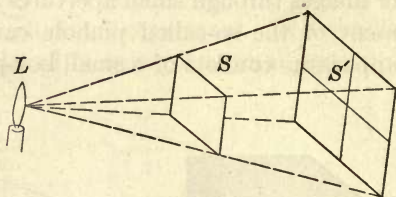


FIG. 431

$$\text{intensity at } S : \text{intensity at } S' = d'^2 : d^2$$

in which d is the distance of screen S from L , and d' the distance of S' from L .

EXERCISES. 1. How does the quantity of light on screen S compare with that on S' ?

2. Suppose that S is 2 ft. from L , and S' 4 ft. How does the intensity of light on screen S compare with that on S' ? How will the intensities on the two screens compare if S' be placed at a distance of 3 ft. from L ?

480. The Photometer. A *photometer* is an instrument for measuring the intensity of light. The unit of intensity is the candle power, which is the light given out by a standard candle. The common incandescent electric light of the carbon filament type is usually of 16 candle power.

The Bunsen photometer, Fig. 432, consists in principle of a paper screen upon which there is a small circular oil or grease

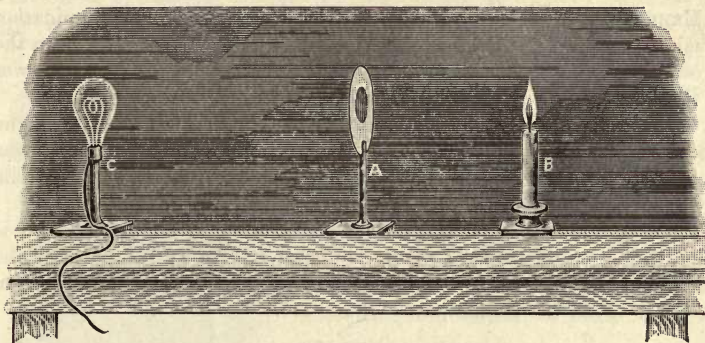


FIG. 432

spot. If the paper with the grease spot upon it be held up to the light, in front of an open window for example, so that the paper is between the light and the eye, the grease spot will appear lighter in color than the paper because it is more transparent. Now if the paper be held up in front of a dark body, such as a blackboard, the grease spot will appear darker than the paper, because it reflects less of the light than does the paper. When the intensity of illumination on both sides of the paper is equal the distinction between the grease spot and the paper is reduced to a minimum.

To determine the intensity of light by means of this apparatus we proceed somewhat as follows: A standard candle is

placed at a given distance from the screen, 1 foot say; the light, the intensity of which is to be measured, is placed on the other side of the screen and then moved back and forth until a position is found at which the spot on the screen is equally illuminated from both sides. From the law of inverse squares we may now determine the intensity of the given light in terms of its distance from the screen. If the candle is 1 foot from the screen and the light 4 feet distant, their relative intensities are as $1^2:4^2$, that is, as 1:16. Thus we say that the intensity of the light L is 16 candle power.

EXERCISES. 3. A lamp placed 3 ft. from a screen gives an illumination equal to that of a standard candle placed at a distance of 1 ft. from the screen, lamp and candle being on opposite sides. Find the candle power of the lamp.

4. A gas jet and an electric lamp are placed on opposite sides of the screen so that the spot upon the latter is equally illuminated. The gas jet is 2 ft. from the screen; the electric light 6 ft. Compare the candle power of the two sources.

5. It is desired to find the candle power of a given arc light. It is found that when a standard candle is placed 1 ft. from the screen of the photometer the latter has to be removed to a distance of 30 ft. from the arc light. Find the candle power of the arc.

REFLECTION

481. The Law of Reflection. If a beam of light from a

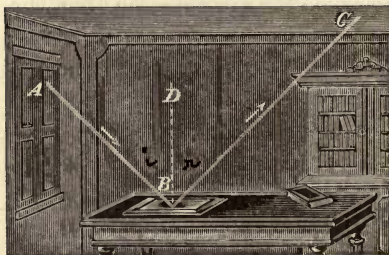


FIG. 433

source A , Fig. 433, fall upon a polished surface it will be reflected to C . The line BD is drawn perpendicular to the surface of the mirror and is called a normal. The angle ABD , formed by the incident ray and the normal, is called the *angle of incidence*; the angle DBC , formed by the reflected ray and the normal, is the *angle of*

formed by the reflected ray and the normal, is the *angle of*

reflection. A diagrammatic representation of the angle of incidence i , and the angle of reflection r , is that of Fig. 434.

The law: *The angle of incidence is equal to the angle of reflection, and both lie in the same plane.*

482. Mirrors and Images. A *mirror* is any polished surface. Images formed by mirrors are of two kinds, real and virtual. *Experiment.* (a) If a candle be held between the center of curvature of a spherical mirror and its focus, there will appear on the screen a *real image*; that is, an image formed by the

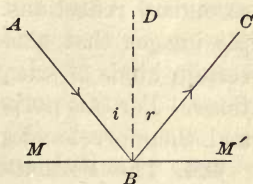


FIG. 434

actual focusing of the rays of light. *Experiment.* (b) If now the candle be placed in front of a plane mirror, a *virtual image* will be formed and will appear to be as far back of the mirror as the candle is in front of it. A virtual image is one which appears to be where it really is not. All images formed in plane mirrors are virtual images.

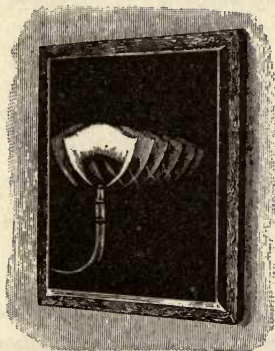


FIG. 435

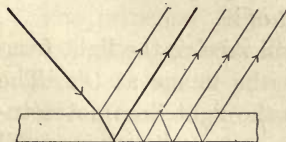


FIG. 436

483. Multiple Images. If an object such as a candle flame or a gas flame be held close to a plate glass mirror and viewed at an angle, a series of images may be observed, Fig. 435, the second being the brightest one of the series. These are called *multiple images*, and their formation is explained by the fact that the light from the object is reflected

from the mirror to the eye from both surfaces, as shown in Fig. 436. The first and rather faint image which appears is due to the reflection from the surface of the glass. The sec-

ond and brightest image is due to the reflection from the silvered rear surface. The other and fainter images are due to secondary reflections. It is because of the formation of multiple images that glass mirrors cannot be successfully used in certain kinds of scientific work, such as astronomical observations. For this purpose mirrors made of highly polished metal, and therefore having but a single reflecting surface, are used.

484. The Formation of Images in Plane Mirrors. Given an object in front of a plane mirror to find the position and character of the image. Let O , Fig. 437, be an object in front of the mirror. Draw from this point two rays incident upon the mirror at m and m' . Erect the normals ma and $m'b$. Now

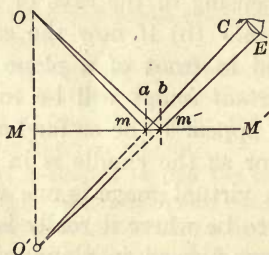


FIG. 437

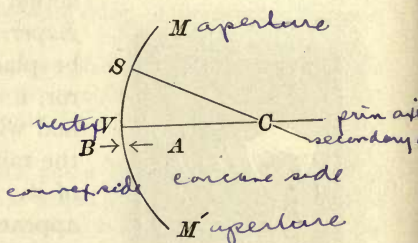


FIG. 438

draw the line mC and $m'E$ in such a way that in each case the angle of incidence is equal to the angle of reflection. Produce the lines Cm and Em' until they meet at the point O' . It may be shown by geometry that O' lies on the perpendicular and is as far back of the mirror as O is in front of it.

Now if an eye be placed at CE it will receive the light from the object O , but will appear to see the image at O' . The image at O' is of course virtual, since the light does not actually focus at that point. If the eye be removed no image will exist.

485. Spherical Mirrors. A spherical mirror is formed from a portion of a spherical shell, a section of a spherical mirror being shown in Fig. 438. The opening MM' is called the *aper-*

ture of the mirror. A point midway between M and M' is the *vertex* V . The *center of curvature* of the mirror C is the center of the sphere of which the mirror is a part. A *principal axis* is a straight line passing through the center of curvature and through the vertex. A *secondary axis* is any other straight line passing through the center of curvature and cutting the mirror at any point other than at V . The line CV is a principal axis; the line CS is a secondary axis. When we consider a spherical mirror from the concave side A , it is called a *concave mirror*; when we look at it from the convex side B it is called *convex mirror*.

486. The Principal Focus in Spherical Mirrors. The *principal focus of spherical mirrors* is the point at which rays parallel

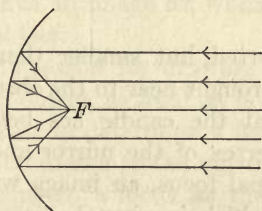


FIG. 439

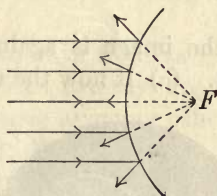


FIG. 440

to the principal axis come to a focus, Fig. 439. For concave mirrors this focus is real and a point, as may be shown by allowing the sun's rays, which are nearly parallel, to fall upon the mirror.

The principal focus of a convex mirror is a virtual focus and is the point at which rays parallel to the principal axis appear to come to a focus, Fig. 440.

487. Relation of Image and Object in Spherical Mirrors.

Experiment. (a) If a candle be placed on the principal axis and between the center of curvature and the principal focus of a spherical mirror, a real image will appear upon the screen Fig. 441. The image is inverted, real, and larger than the object. (b) If now the candle be placed in the position of the

screen and a small screen be placed in the original position of the candle, a small but very bright image will appear. In this

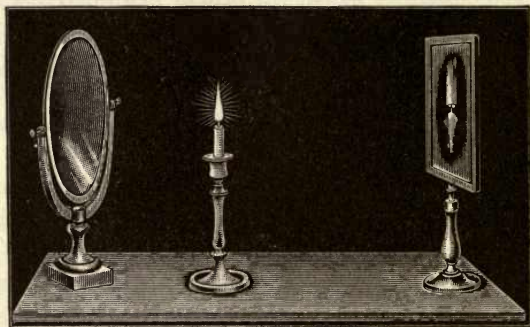


FIG. 441

case the image is again real, inverted, but smaller than the object. (c) If now the mirror be brought near to the observer,

so that the candle lies between the vertex of the mirror and the principal focus, an image will be seen which is virtual, erect, and larger than the object, Fig. 442.

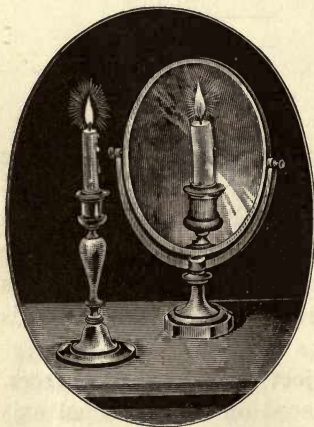


FIG. 442

It thus appears that for some cases the relation of the image to the object may be determined experimentally. It is sometimes of importance, also, to determine this relation graphically. Suppose that we wish to determine graphically the position and character of the image when the object is placed between the center of curvature and the principal focus, as

in Experiment (a). Let the arrow AB , Fig. 443, represent the object. First, from the point A draw a line AD parallel

to the principal axis. This line will be reflected through the principal focus in the direction of Da . From the point A draw a second line AC through the center of curvature to the mirror. Since this line is normal to the mirror, it will be reflected back upon itself, thus forming at a a focus which will represent the point of the image corresponding to A . Now draw two similar lines from the point B . These lines will come to a focus at the point b , forming the base of the image. Thus we have an image ab , which is real, inverted, and larger than the object.

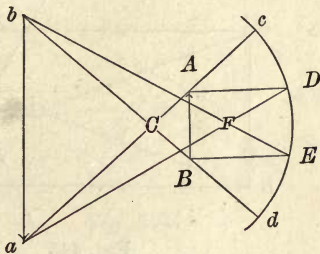


FIG. 443

The reason for drawing at least two rays from each point in the object, as from A , is because at least two rays are always required to determine a focus. Of course as many other rays may be drawn to the mirror as desired; these, however, would all come to a focus at the point a , but would only serve to confuse the figure.

In determining the relation of the object to the image in spherical mirrors, there are seven important cases, which should be drawn and explained as outlined in the following topic.

488. Object and Image in Spherical Mirrors. 1. Given an

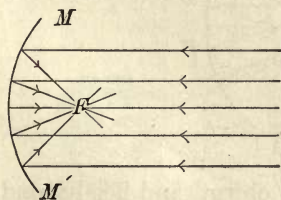


FIG. 444

object at an infinite distance from a concave mirror to find the position and character of the image. Since the rays of light from the object are parallel to the principal axis, the image formed in this case will be real and a point at the principal focus, Fig. 444.

2. Given an object at a finite distance beyond the center of curvature to find the position and character of the image.

The image is real, inverted, smaller than the object, and lies between the principal focus and the center of curvature, Fig. 445.

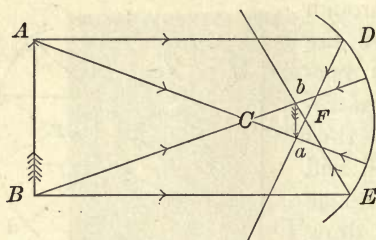


FIG. 445

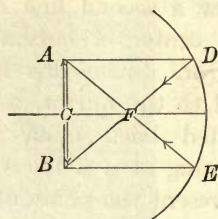


FIG. 446

3. Object at the center of curvature. Since in this case we cannot draw a ray through the center of curvature we may determine the position and character of the image by drawing, first, from the object to the mirror, rays parallel to the principal axis and thence back through the principal focus, and second, drawing rays from the object to the mirror through the principal focus and thence back parallel to the principal axis. It thus appears that the image is real, inverted, and lies upon the object at the center of curvature, Fig. 446.

4. Object between center of curvature and principal focus. It will be observed that this is the reciprocal of case 2. The

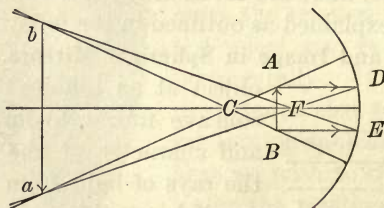


FIG. 447

image is real, inverted, larger than the object, and lies beyond the center of curvature, Fig. 447.

5. Object at the principal focus. This is the reverse of case 1. Since the rays reflected from the mirror are parallel,

the image would theoretically be at an infinite distance away. This means of course that no image will be formed, Fig. 448.

6. Object between the principal focus and the mirror. The rays reflected from the mirror are divergent and hence will never come to a focus, and no real image will therefore be formed. In case an eye be stationed in front of the mirror a virtual image will be formed back of the mirror.

That is, in this case the image is virtual, erect, larger than

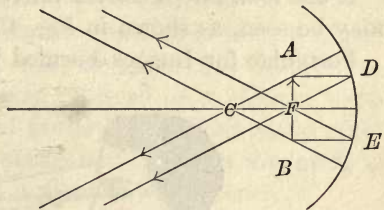


FIG. 448

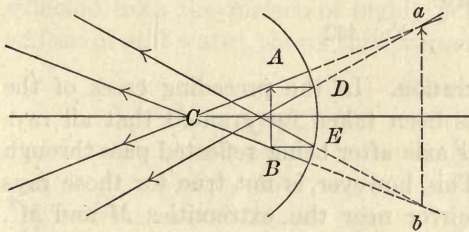


FIG. 449

the object, and appears to lie back of the mirror, Fig. 449.

If a spherical mirror be brought near to the face so that the eye lies between the principal focus and the mirror a virtual and magnified image of the face may be obtained, as

illustrated in Fig. 450.

7. Object in front of convex mirror. In this case also the

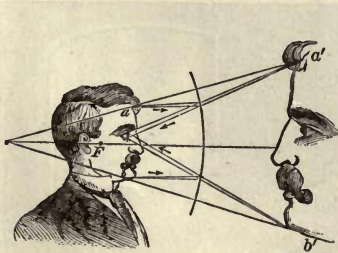


FIG. 450

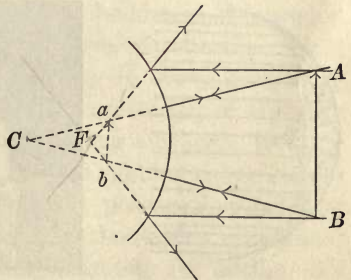


FIG. 451

image is virtual, smaller than the object, and appears to lie between the mirror and the principal focus, Fig. 451.

If one look into a convex mirror a minified and virtual image may be seen, as shown in Fig. 452.

Formulae for Images Formed by Mirrors, Supplement, 587.

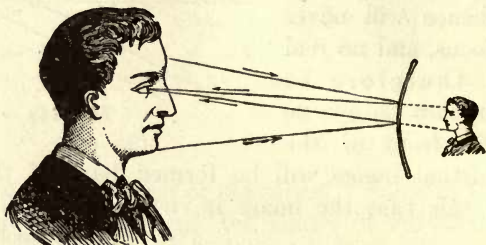


FIG. 452

489. Spherical Aberration. In the preceding cases of the spherical mirror, it has been taken for granted that all rays parallel to the principal axis after being reflected pass through the principal focus. This, however, is not true for those rays which fall upon the mirror near the extremities M and M' . The reflected rays for this portion of the mirror shown in Fig. 453 do not pass through the principal focus. This failure of part of the light to pass through the principal focus is called *spherical aberration*.

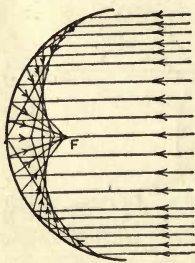


FIG. 453

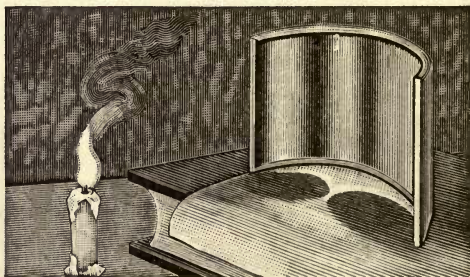


FIG. 454. — Caustic

Spherical aberration in the case of a spherical reflecting surface gives rise to a curved line of light called the *caustic*. A caustic curve can be demonstrated experimentally by allowing rays of light to fall upon the concave surface of a strip of polished metal (bright tin) bent into the form of a circular arc, Fig. 454, the reflected light being received on a piece of white paper upon which the strip of metal rests. This same effect may be seen by allowing the sunlight to fall upon the inside of a gold finger ring placed upon a piece of white paper.

490. Diffused Light. If a beam of light fall upon a smooth surface it will be regularly reflected, as shown in Fig. 455. If this light be received by the eye, the latter will see not the reflecting surface, but the source of light. For example, light reflected from the surface of highly polished furniture, or the surface of still water, shows this property.

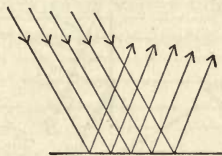


FIG. 455

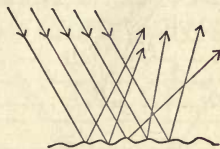


FIG. 456

If, on the other hand, a beam of light fall upon a body having an irregular surface, such as a piece of white paper or the wall of a room, the light is scattered in all directions, Fig. 456. This is called diffused light. It must not be imagined, however, that diffused light does not obey the laws of reflection, for it does, the angle of reflection for each ray in every case being equal to the angle of incidence. The scattering of the rays is due to the irregularities in the reflecting surface. It is by means of this diffused light that we are enabled to see clearly the outline of bodies. If every object possessed a polished surface we would see only the light of the source and would not be able to make out clearly and definitely the outline and nature of the reflecting surface.

REFRACTION

491. Refraction. Experiment. If a beam of light be allowed to fall upon the surface of water at O , Fig. 457, part of it will be reflected to E , according to the laws of reflection, and a part will be refracted to B . *Refraction is the bending of a ray of light due to passing from a medium of one density to that of another density.* The angle i is the angle of incidence, the angle COB is the angle of refraction, and BOD the angle of deviation.

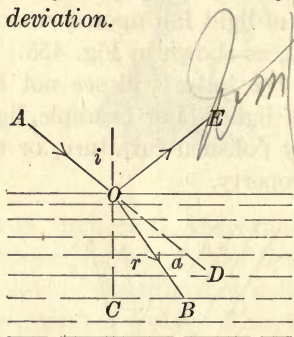


FIG. 457

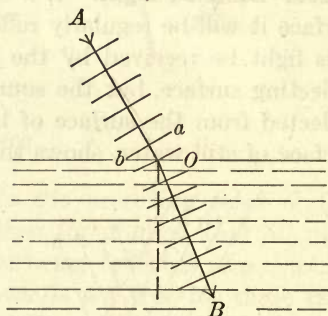


FIG. 458

492. Explanation of Refraction. Imagine a series of wave fronts advancing in the direction AO , Fig. 458. When the portion of the wave marked b strikes the surface of the water its speed is retarded; a , therefore, moves faster than b , hence the wave front is bent downward, as shown, and the direction of the motion is changed from AO to OB . After a wave once passes into a medium both portions of the wave front, a and b , move forward with the same speed; therefore the line of direction OB is a straight line. Refraction of light is due to a change in velocity of one portion of a wave front as compared with that of another, as the wave passes from one medium to another of different density.

493. Illustrations of Refraction. Experiment. If a coin be

placed in the bottom of a cup so that it lies just beyond the range of vision, Fig. 459, and the cup then be filled with water, the coin will gradually come into view. This is due to the fact that the ray of light from the coin to the eye is bent away from the normal at the surface. The eye in looking along the line appears to see the coin as if elevated.



FIG. 459

If the stick be thrust into water in the direction *A*, Fig. 460, it will appear to be bent away from the observer; if it be thrust in the direction *B* it will appear to be bent toward the observer. The refraction of light thus not only accounts for the apparent bending of the stick, but also for the fact that the bottom of a vessel containing water, or the bottom of a pond, appears to be nearer the surface than it really is. Both

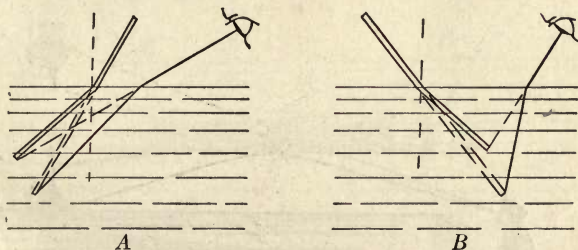


FIG. 460

the apparent displacement of an object and the shoaling of water are well illustrated by Fig. 461. To the boy on the bank the fish which is at *b* appears to be at *a*. To the man on the bridge the distance from the surface of the water to the fish appears to be less than it really is. When looking vertically downward at the bottom of a vessel filled with water the apparent distance from the surface to the bottom is three-fourths of the true distance. This may be shown by looking at the

bottom of a tall glass vessel filled with water. If the finger be placed on the side of the vessel at the point where the bottom

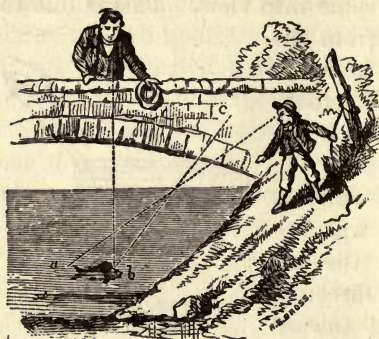


FIG. 461

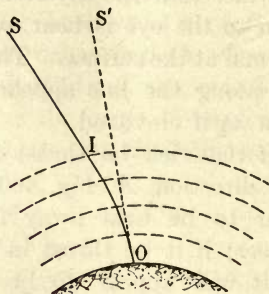


FIG. 462

appears to be, it will be found that the point touched by the finger will be about three-fourths the entire depth of the water.

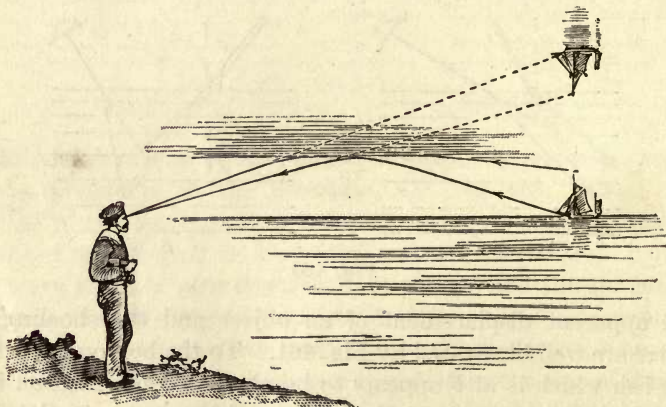


FIG. 463. — Mirage

494. Refraction in Air. An interesting illustration of refraction occurs in the bending of the rays of light in passing through portions of the atmosphere having different densities. A ray

of light, for example, from the star S will be refracted in passing from one layer of air to another, as shown in Fig. 462. An observer on the earth at O will appear to see the star in the position S' . The apparent position of the body is higher than its real position. It thus frequently happens that the sun is visible while yet actually below the horizon.

The mirage is a phenomenon frequently observed in deserts, in which the traveler sees the image of distant objects, such as palm trees, etc., usually by refraction. The explanation of the mirage lies mainly in the fact of the refraction of light through layers of air of different density. A phenomenon somewhat similar to the mirage of the desert is occasionally seen at sea in still, hot weather, in which the image of a distant ship appears in the sky, sometimes upright, sometimes inverted, as shown in Fig. 463.

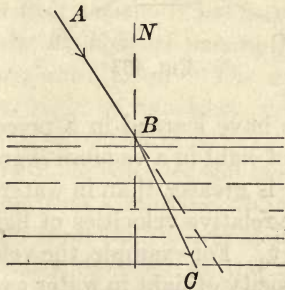


FIG. 464

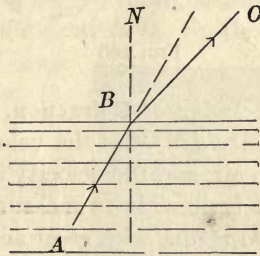


FIG. 465

495. The Law of Refraction. When a ray of light passes from a rare to a dense medium, as from air to water or glass, it is bent toward the normal, Fig. 464; when it passes from a dense to a rare medium it is bent away from the normal, Fig. 465.

496. Refraction of a Ray through a Parallel Plate. Let a ray of light AB , Fig. 466, be incident upon the surface of a piece of plate glass at the point B . Let BD represent the refracted ray. At B the ray is bent toward the normal as it passes into the denser medium, and at C it is bent away from

the normal as it passes out. The refraction at C is equal to that at B and in the opposite direction. The ray CD is therefore parallel to AB . When a ray passes through a parallel plate its direction is unchanged; it suffers only lateral displacement.

497. Refraction of a Ray through a Prism. *Experiment.* Let a ray of light fall upon a prism as shown in Fig. 467. On entering the prism it is bent toward the normal and on emerging it is bent away from the normal. An eye will, therefore, appear to see the object as if elevated in line with the refracted ray.

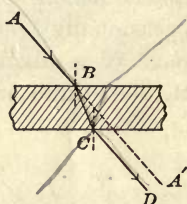


FIG. 466

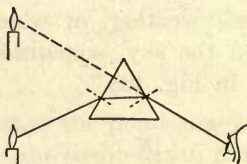


FIG. 467

498. Index of Refraction. We have learned in a preceding topic (Art. 476) that the velocity of light in a vacuum is greater than in air, and the velocity in air is greater than in water, etc. Now it is possible to measure the relative velocities of light in any two media with great accuracy. For example, the velocity of light in a vacuum is to the velocity of light in water as 4 : 3; that is, the velocity of light in air is 1.333 times as great as in water.

The index of refraction of any substance may be defined, then, as the ratio of the velocity of light in a vacuum to the velocity of light in that substance. (Supplement, 589.) The index of refraction of water is 1.33; crown glass 1.53; flint glass 1.61; diamond 2.47.

499. Critical Angle. Consider a source of light at A in the medium water, Fig. 468. A ray from A to B will be reflected away from the normal to C . For this ray the angle of inci-

dence is ABN' and the angle of refraction CBN . A ray of light from E to B will be refracted along the surface of the water to D . In this case the angle of incidence is EBN' and

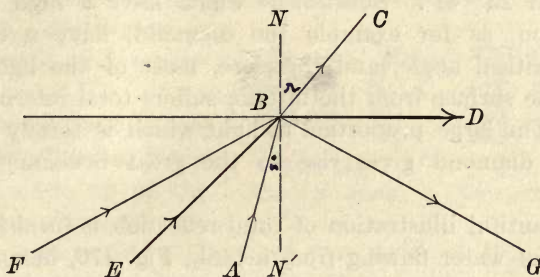


FIG. 468

the angle of refraction DBN is 90° . The angle EBN' is called the *critical angle*. When we speak of the critical angle we always consider the light as passing from the dense to the rare medium, as from water to air. The critical angle is an angle of incidence such that the angle of refraction is 90° .

Now if we consider the ray of light as coming from a source F , the ray will not emerge from the surface at all, but will be totally reflected at the point B in the direction BG . A person standing at F and looking at the surface of the water at B will see the bottom at G ; that is to say, the surface of the water will act like a plane mirror.

500. Total Internal Reflection. When the angle of incidence of a ray of light passing from a dense to a rare medium is greater than the critical angle, we have total internal reflection. If a spoon be placed in a tumbler of water and the surface of the water be viewed from



FIG. 469

below at an angle greater than the critical angle, the spoon may be seen by reflection from the surface, Fig. 469. The critical angle for water is $48^{\circ} 30'$; for flint glass $38^{\circ} 41'$; for diamond $23^{\circ} 41'$. Substances which have a high index of refraction, as for example the diamond, have a relatively small critical angle, and therefore, most of the light falling upon the surface from the interior suffers total internal reflection. The large proportion of light which is totally reflected in the diamond gives rise to the great brilliancy of this gem.

A beautiful illustration of total reflection is furnished by a stream of water flowing from a tank, Fig. 470, having in the

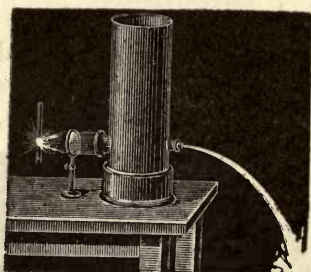


FIG. 470

side opposite the orifice a lens by means of which a strong beam of light from the sun or an electric arc may be concentrated within the jet. The light strikes the interior surface of the stream of water at an angle greater than the critical angle and thus suffers total internal reflection. The light is held within the stream until, after repeated reflection, it strikes the bottom of the receptacle,

where it shows as a bright spot. A goblet held in the stream is filled with bright light, which gives rise to the name "fountain of fire." The brilliant display seen in electrical fountains depends upon this principle.

LENSES

501. The Lens. *A lens is a transparent medium having two curved surfaces or one curved and one plane surface. There are two general classes of lenses, convex and concave.*

A *convex lens* is one that is thicker at the middle than at the edges. Convex lenses are divided into three sub-classes, as

shown in Fig. 471; namely, *double-convex*, *plano-convex*, and *concave-convex*.

A *concave lens* is one that is thinner at the middle than at the edges. Concave lenses are also divided into three sub-classes, Fig. 472, *double-concave*, *plano-concave*, and *convex-concave*.

502. Terms Used in Connection with Lenses. Since a lens is made up of the intersection of two spheres,



FIG. 471
Convex Lenses



FIG. 472
Concave Lenses

or of one sphere and a plane, we may speak of the *center of curvature* of the lens as the center of the sphere of which its face is a part. Since a lens always has two faces, it therefore

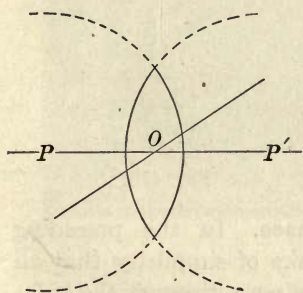


FIG. 473

always has two centers of curvature. A straight line PP' , drawn through the centers of curvature of a lens, is called the *principal axis*, Fig. 473. The *optical center* of the lens O is a point through which a ray may pass without having its direction changed. In double-convex and double-concave lenses, having surfaces of equal curvatures, the optical center is at the center of

the lens. In some cases, however, the optical center may lie entirely outside the lens. In this text we shall consider in every case lenses having optical centers at their geometric centers.

The *principal focus* of a lens is the point on the principal axis at which rays parallel to the principal axis come to a focus. The distance from the principal focus to the optical center is the *focal length* of the lens.

503. The Relation of the Thickness of a Lens to its Focal Length. The effect of the curvature of a lens upon parallel

rays of light is illustrated in Fig. 474. The lens having the greater curvature, that is, the thick lens, has the shorter focal length. This effect of the curvature of the lens upon its focal length may be expressed by the statement, the thicker the lens the shorter its focal length.

504. The Effect of Lenses on Parallel Rays. Since rays of light falling upon a lens are bent toward the normal on entering the lens and away from the normal on leaving it, the general effect of lenses may be stated as follows: (a) *Convex lenses are convergent*; they cause the rays of light to come to a focus, Fig. 475. (b) *Concave lenses are divergent*, Fig. 476.

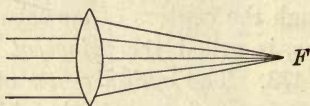
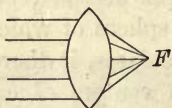


FIG. 474

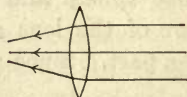


FIG. 475

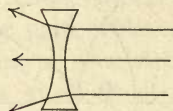


FIG. 476

505. Spherical Aberration in Lenses. In the preceding topics it has been assumed for the sake of simplicity that all rays which pass through the lens also pass through the principal focus. This, however, is not the case. In thick convex lenses those rays which pass through near the edge of the lens cross the principal axis nearer the lens than do those rays which pass through near the principal axis, Fig. 477.

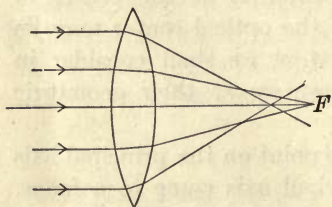


FIG. 477

This failure of all the rays to pass through a common point produces a blurring of the image. *Spherical aberration* is the blurring of the image due to

the failure of the marginal rays to pass through the principal focus.

Spherical aberration in a lens may be remedied by cutting off the marginal rays by means of a screen or diaphragm. The use of a diaphragm makes the image sharper in outline, but less bright. In large lenses, such as are used in telescopes, spherical aberration is diminished by making the curvature of the lens less toward the edge, thus tending to bring all parallel rays to the same focus.

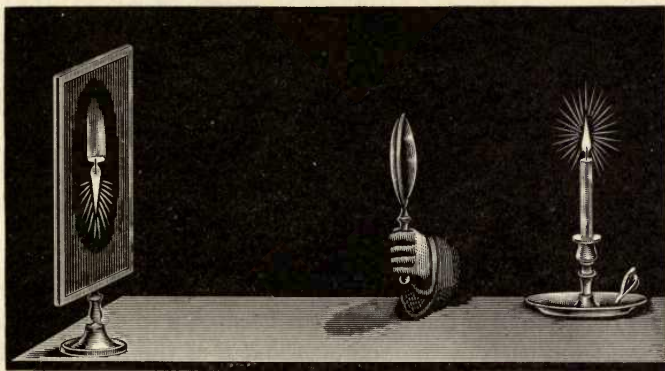


FIG. 478

506. Illustration of Images Formed by Lenses. *Experiment.* (a) Place a candle some distance from a screen in a darkened room. Next place a convex lens between the candle and the screen, and relatively near the candle. Adjust the position of the lens until a clear image of the candle is thrown upon the screen, Fig. 478. The image is real, inverted, and larger than the candle. *Experiment.* (b) Now change the position of the lens, keeping it between the candle and the screen, but relatively near the screen. A second position will be found at which an image again appears upon the screen. In this case the image is real, inverted, and much smaller than the object.

Thus, as in the case of the mirror, the size of the image formed by a lens depends upon its position with respect to the object and the screen.

507. To Find by Drawing the Position and Character of the Image. Suppose that the object be placed beyond the principal focus F , as exemplified by Experiment (a) of the preceding topic. Fig. 479 illustrates the relative position of the lens with

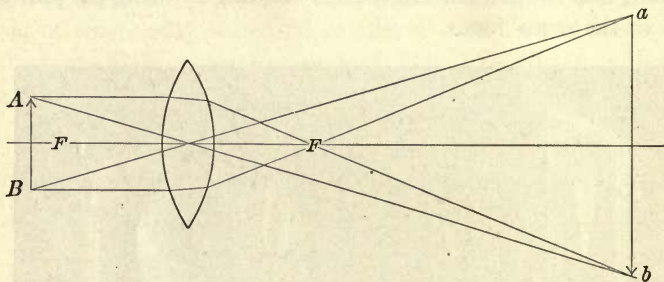


FIG. 479

respect to the object AB . Now in order to determine the position and character of the image, it is necessary to draw at least two rays from each of the points A and B of the object to the lens. We select two rays the direction of which can readily be determined; these are respectively a ray parallel to the principal axis, which after refraction passes through the principal focus F in the direction Fb , and the ray Ab passing through the optical center. In a like manner we draw from the point B two similar rays, one passing through the principal focus and the other passing through the optical center. Thus we have formed at ab a graphic representation of the image. It is real, inverted, and larger than the object.

508. Relation of Image to Object. There are seven general cases illustrating the relation of the image formed by the lens to the object. These cases may be demonstrated graphically as follows:

1. Given an object at a great distance from the lens such

that the rays from the object to the lens are parallel to the principal axis, to find the position and character of the image.

The image is real, a point, and lies at the principal focus, Fig. 480.

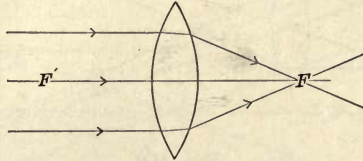


FIG. 480

2. Given an object at a finite distance from a lens greater than twice the focal distance to find the position and character of the image. The image is real, inverted, smaller than the object, and lies beyond the principal focus, Fig. 481.

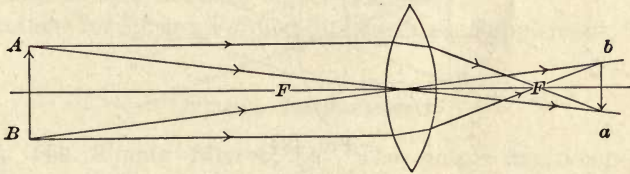


FIG. 481

3. Object at twice the focal distance from the lens. The image is real, inverted, the same size as the object, and as far back of the lens as the object is in front of it, Fig. 482.

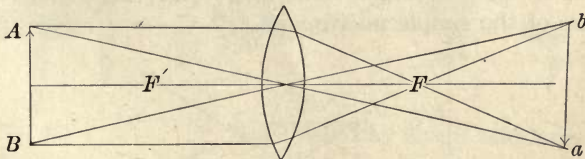


FIG. 482

4. Object at a point less than twice the focal distance, but greater than the focal distance. The image is real, inverted, and larger than the object, Fig. 483.

5. Object at the principal focus. Since the rays are parallel

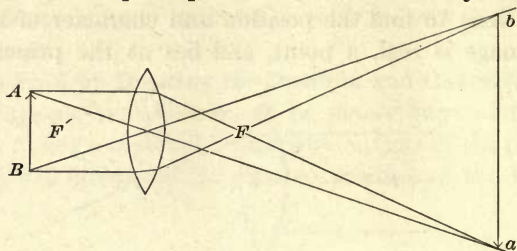


FIG. 483

to the principal axis, the image is formed theoretically at an infinite distance from the lens, Fig. 484. This is the converse of case 1.

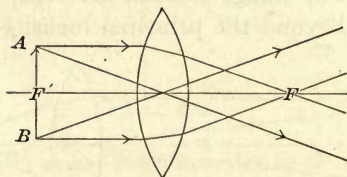


FIG. 484

6. Object between the lens and the principal focus. The rays on leaving the lens are divergent, hence no real image is formed. If an eye be placed in a position to receive these divergent rays, an image will appear to be at ab . This image is virtual, erect, and larger than the object, Fig. 485. This is the case of the simple microscope.

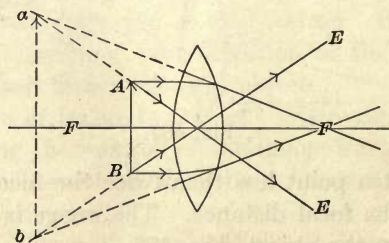


FIG. 485

7. To find the position and character of the image formed by a convex lens. Let AB represent the object. The transmitted rays are divergent, hence no real image will be formed.

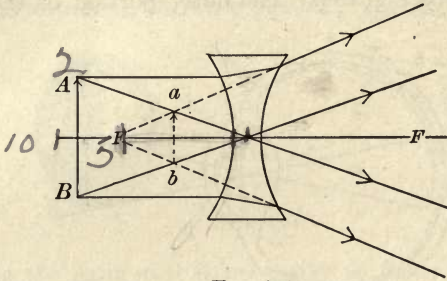


FIG. 486

A virtual image will appear at ab . The image is virtual, erect, and smaller than the object, Fig. 486.

Formulae for Images Formed by Lenses, see Supplement, 588.

OPTICAL INSTRUMENTS

509. The Simple Microscope. The simple microscope or common magnifier, such as is used in examining botanical and



FIG. 487

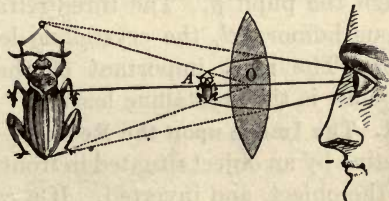


FIG. 488

Magnification by Simple Microscope

zoological specimens and similar objects, Fig. 487, illustrates that case of the convex lens in which the object is placed between the lens and the principal focus (case 6). It gives a virtual and magnified image of the object, Fig. 488.

510. The Eye. We have in the case of the human eye a very remarkable application of the principle of the formation of real images by a convex lens. The characteristic parts of the eye are shown in Fig. 489. The outer portion of the eyeball

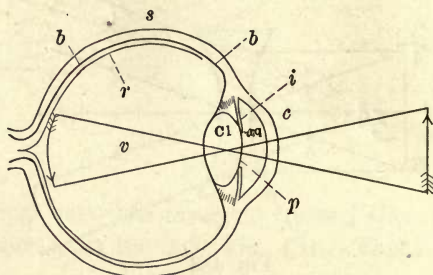


FIG. 489

s, consists of a tough covering called the sclerotic coat; *b* is the choroid coat, containing a black pigment, the function of which is to prevent internal reflection of the light; *r* is the retina, formed by an expansion of the optic nerve; covering the front of the eye is the cornea *c*, a transparent medium; *i* is the iris, which gives the eye its characteristic color and the function of which is to regulate the quantity of light entering through the pupil *p*. The three refracting media are *aq*, the aqueous humor; *cl*, the crystalline lens; and *v*, the vitreous humor. The most important of the three, from an optical viewpoint, is the crystalline lens.

511. The Image upon the Retina. The image formed upon the retina by an object situated in front of the eye is real, smaller than the object, and inverted. If a candle be held in front of an eye taken from a freshly killed animal, it is possible under satisfactory conditions to see the inverted image formed upon the retina, as shown in Fig. 490. The question naturally arises as to why it is that we can see objects erect when the image upon the retina is inverted. The explanation probably lies in the fact that our judgments of the true position of bodies

with respect to each other is based primarily upon experiences other than those of sight. It is said that the blind upon recovering sight often find it necessary at first to use the sense of touch in determining the true position of bodies.



FIG. 490

In using the camera it is necessary to focus the instrument by moving either the screen or the lens back and forth so as to bring the image upon the plate. In the case of the eye, however, this focusing is accomplished automatically by changing the convexity of the crystalline lens. It is very remarkable that we can involuntarily and almost instantly change the shape of the crystalline lens so that the image of an object only a few inches distant, or an object miles away, may be distinctly focused upon the retina.

512. The Abnormal Eye. The three most common defects of the eye are: (a) nearsightedness, (b) farsightedness, (c) astigmatism.

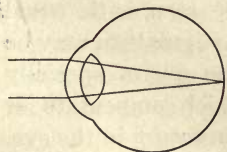


FIG. 491

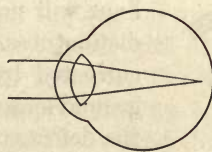


FIG. 492

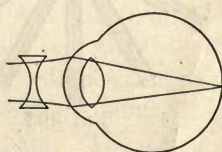


FIG. 493

In the normal eye light from a given object is focused exactly upon the retina, Fig. 491. The *nearsighted eye* is one in which the distance from the lens to the retina is so great that the image cannot be properly focused upon the retina, Fig. 492. Persons having such eyes are said to be nearsighted, because

they have to bring the object very near the eye in order to see it distinctly. Nearsightedness is remedied by the use of concave glasses, which diverge the rays and thus throw the image farther back upon the retina, Fig. 493.

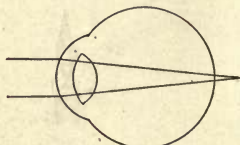


FIG. 494

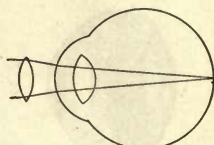


FIG. 495

The *farsighted eye* is one in which the image tends to form beyond the retina, Fig. 494. The remedy for farsightedness lies in the use of convex glasses, Fig. 495.

513. Astigmatism. *Astigmatism* is a defect of the eye due to a distortion of the image on the retina, which may be caused

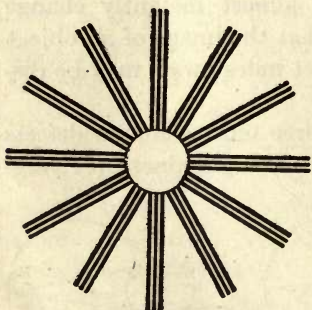


FIG 496

either by irregularities in the shape of the eyeball or a lack of symmetry in the crystalline lens. The defect of astigmatism may be detected by looking at a series of radiating lines, Fig. 496. If the eye be astigmatic the radiating lines will not be seen with equal distinctness. Astigmatism may be corrected by the use of specially ground lenses which compensate for the defects of curvature in the eye.

514. The Visual Angle and Apparent Size of Objects. The *visual angle* is the angle formed by rays passing from the extremities of an object and intersecting at the eye, Fig. 497. The size of this angle depends (a) upon the size of the object and (b) upon its distance from the eye; the greater the distance the less the visual angle. Now the apparent size of an object depends upon the size of the visual angle, because this angle

determines the size of the image formed upon the retina. Therefore the smaller the visual angle the smaller will be the image on the retina, and consequently, the smaller the apparent size of the object. If one look along a railroad track the

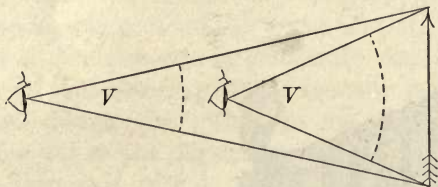


FIG. 497

rails appear to approach each other and the ties to grow shorter, due to the fact that the visual angle diminishes as the distance increases. We are enabled to judge of the real height and size of objects which are at a considerable distance only by calling on our past experiences and judgments.

515. Distance of Distinct Vision. Distinctness of vision depends upon the size of the image formed on the retina; therefore it may be assumed that the nearer an object is brought to the eye the more distinct it will become. Common experience teaches us that this is true only within certain limits, which may be determined by experiment. If the page of a book be held off at arm's length the printed matter will not be distinct enough for most people to read with ease. Upon bringing the book gradually nearer, however, the type will become more distinct as the page approaches, up to a certain point, from which position it will gradually grow dim again. The distance at which the type appears most distinct is called the distance of distinct vision; it is for most normal eyes about 10 inches or 25 centimeters. The limit of distinct vision is determined by the power of the crystalline lens to change its shape and thus focus the image upon the retina.

516. The Camera. The photographer's camera is an instrument used for the printing of pictures by the action of light

upon chemically prepared films. It consists of a light-proof box having an adjustable lens, Fig. 498. The essential features of the camera consist of the adjustment of the lens L ,

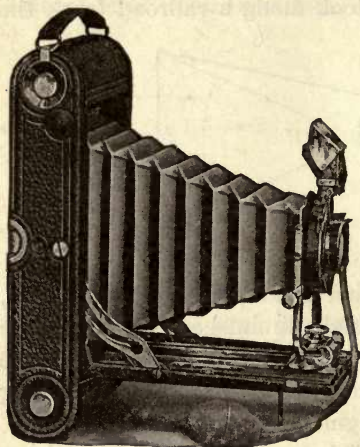


FIG. 498

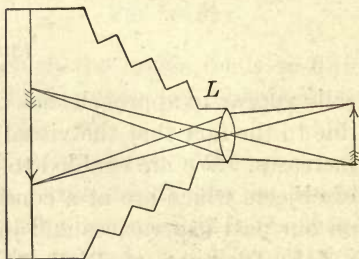


FIG. 499

Fig. 499, until a sharp image of the object to be photographed is formed upon the film. The image formed in the camera is real and inverted.

Compound Microscope, Telescope, and other Optical Instruments, see Supplement, 590 and 591.

517. Duration of Visual Impressions. The duration of a visual impression depends on the sensitiveness of the retina and the intensity of the light, the average time being estimated as about half a second. Distinct impressions, therefore, cannot be made upon the retina unless they succeed each other at intervals greater than that of the duration of visual impressions for the given individual. It is this persistence of impressions on the retina that makes a swiftly moving object appear as a continuous line. Thus the spokes of a rapidly revolving wheel appear to blend into one another, and in a similar manner a burning stick whirled rapidly around at night gives the

impression of a continuous circle of flame. For this reason, also, shooting stars appear to have luminous tails behind them, and an electric arc lamp, fed with an alternating current of frequency greater than 25 cycles per second, appears to give a continuous light. If the arc be photographed, however, on a rapidly moving plate, it will be found that the light is extinguished, that is, diminishes to zero intensity, with every reversal of the current, thus showing that it is really discontinuous.

518. Visual Judgments. The eye has been likened to a camera, and so far as the physical principles involved are concerned, the likeness is very striking. The impressions received from the eye, however, are quite different from those given by a photograph, and for two reasons. In the first place a photograph gives a picture of an object in a given position, while the brain receives

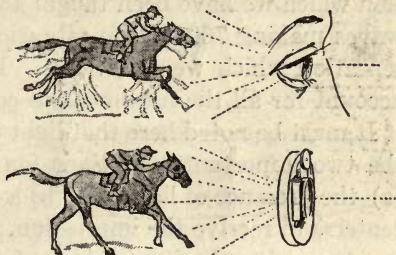


FIG. 500

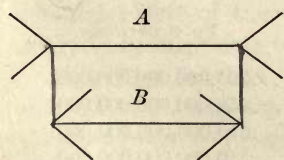


FIG. 501

from the eye a composite impression. The difference between these two effects is very well shown in the comparison of a snap-shot photograph of a horse in the act of running, with that of a simultaneous impression received from the eye, Fig. 500. And in the second place, our judgments of the position, size, and form of objects depend not only upon the images formed by the eye, but also, as has already been explained in Art. 514, upon our past experience. Sometimes our judgment is at fault, however, giving rise to optical illusions of various sorts. Thus in Fig. 501 the two horizontal lines are of exactly the same length. Line A appears to be longer than B because of the effect of the oblique lines at the ends.

COLOR AND DISPERSION

519. Color. *Color is a sensation which depends upon the nature of the light falling upon the retina.* The color which a given light is capable of producing depends upon its wave length, red being due to the longest wave length and violet to the shortest. We cannot properly speak of red light or blue light, since the waves which give rise to those colors are in themselves colorless. When light waves making 395 trillion vibrations per second fall upon the retina they give rise to a sensation which we have been taught to call red; and likewise, light waves making 760 trillion vibrations per second give rise to a sensation which we call violet. In a similar manner we can account for all the intermediate color sensations.

It must be noted here that light is the cause of color and that the two important conditions for the production of color are (a) the presence of light and (b) a sensorium (nerves and nerve centers) to receive the impression. If there were, therefore, no eye to receive the impressions of the light waves, there would be no color.

The following table gives a list of the colors of the solar spectrum, together with the wave lengths and vibration rate of each.

		Length of waves in millimeters	No. of vibrations per second
Red	.....A	......000760	.....395,000,000,000,000
Orange	....C	......000656	.....458,000,000,000,000
Yellow	....D	......000589	.....510,000,000,000,000
Green	....E	......000527	.....570,000,000,000,000
Blue	....F	......000486	.....618,000,000,000,000
Indigo	....G	......000431	.....697,000,000,000,000
Violet	....H	......000397	.....760,000,000,000,000

520. The Spectrum. *Experiment.* If a beam of white light from the sun or an electric arc be allowed to pass through a prism, the light will be broken up into Newton's seven colors of the solar spectrum. A spectrum is a color or series of colors

of which the light from a given source is composed. This breaking up of white light into prismatic colors is called dispersion. It will be observed from Fig. 502 that the red is

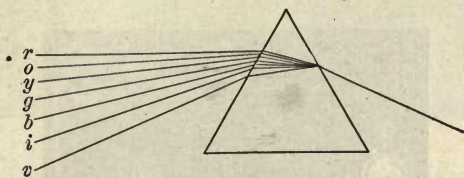


FIG. 502. — Dispersion of White Light

least refracted and the violet most. The colors of the solar spectrum are, in order of their refraction: red, orange, yellow, green, blue, indigo, violet.

We have seen that the solar spectrum consists of seven colors ranging from red to violet. Every substance when heated to incandescence has its own characteristic spectrum, depending upon the physical condition of the body. There are three kinds of spectra, as shown in Figs. 503, 504, 505. The first is a spectrum of the sun, showing the dark bands characteristic of the solar spectrum. The second, Fig. 504, is a continuous spectrum formed by light from the electric arc. The third is very appropriately called a bright-line spectrum. The characteristics of the three kinds of spectra will be discussed more fully in a later topic.

521. The Rainbow. One of the most familiar and striking examples of dispersion is that seen in the rainbow. In order to see a rainbow three conditions are necessary: (a) There must be drops of water in a cloud or mist; (b) the sun must be shining on the cloud; and (c) the eye of the observer must be in such a position as to receive the refracted light from the raindrop; that is, the observer must stand with his back to the sun.

A rainbow may be formed experimentally as follows: Allow a strong beam of light from the sun or an electric lantern to pass through a circular opening in a screen and fall upon a spherical

flask full of water, Fig. 506. The flask represents a large drop of water in which the light is both refracted and reflected; that is, it is refracted on entering the flask and reflected from

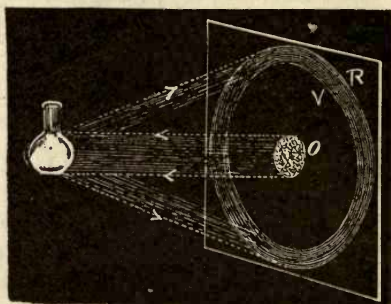


FIG. 506

the rear surface, being thus thrown back upon the screen, forming a circular band of color, red on the outside and violet on the inside. This colored band upon the screen, formed by the displacement of white light by the spherical flask, is somewhat analogous to the formation of the rainbow.

There are two rainbows, the primary and the secondary, Fig. 507. The *primary bow*, which is the one usually observed, is much the brighter of the two and lies inside the secondary. In the primary bow the red is on the outside and the violet on the inside. The *secondary bow* is the fainter of the two, and in fact is not usually seen except under very favorable conditions. Its colors are reversed as compared with those of the primary, the violet

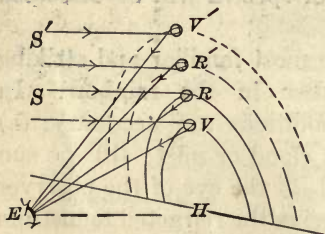


FIG. 507

being on the outside and the red on the inside.

Theories explaining the formation of the colors of the rainbow are quite complex and have given rise to no little discus-

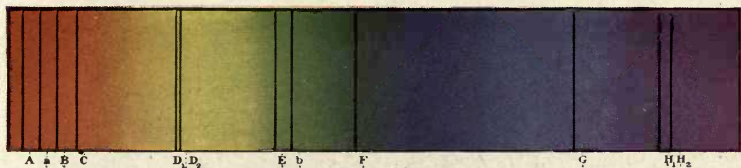


Fig. 503. Solar Spectrum. Crossing this spectrum there are many dark lines which are called Fraunhofer lines. Such a spectrum is very appropriately called a Dark Line Spectrum. These lines, however, are not visible under ordinary conditions without the aid of a spectroscope.



Fig. 504. Continuous Spectrum. The colors of a continuous spectrum blend one into the other without any dark lines occurring, as in the case of the spectrum of Fig. 503. A continuous spectrum is due to incandescent solids, such as the carbons of the electric arc, or the glowing filament of an incandescent lamp.

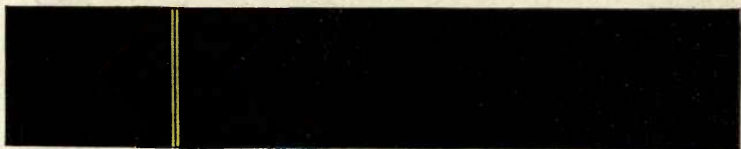


Fig. 505. Bright Line Spectrum. A bright line spectrum is formed by the light from an incandescent gas. Each metal, for example, when in a volatile condition and heated to incandescence gives rise to its own characteristic bright line spectrum, the above being that of sodium.

sion. We have reason to believe that the order and character of the colors are due to three main causes: (a) reflection, (b) refraction, (c) dispersion, and in some cases to a fourth cause (d) interference phenomena. (Supplement, 594.)

522. Continuous Spectrum. There are three kinds of spectra: (a) continuous, (b) bright-line, and (c) dark-line. A *continuous spectrum* is one in which the colors blend gradually from one into the other without any break. The spectrum from an arc lamp is continuous, the colors grading continuously from red to violet. An incandescent solid gives a continuous spectrum. The spectrum from a gas flame, or a candle flame, or the flame of a kerosene lamp are in all cases continuous, the luminous properties of such flames being due to the red-hot solid particles which they contain. Likewise a platinum wire or any other metal heated to incandescence gives a continuous spectrum.

523. Bright-line Spectrum. A *bright-line spectrum* is one consisting of one or more bright lines. A bright-line spectrum is formed from an incandescent gas. Thus if a piece of sodium be placed in the flame of a Bunsen burner and the yellow light examined by means of a spectroscope, a single yellow band will appear. This is a bright-line spectrum. So long as a substance remains in the state of an incandescent solid it gives a continuous spectrum; the moment, however, that it becomes gasified and incandescent, it gives a bright-line spectrum.

524. Dark-line Spectrum. A *dark-line spectrum* is one in which dark lines appear at intervals across the color band of which the spectrum is composed. Such a spectrum is formed when the light from an incandescent solid passes through that of an incandescent gas. The solar spectrum is a dark-line spectrum. It is true that it appears to the naked eye to be continuous. If, however, the solar spectrum be examined by means of a spectroscope, it will be found that many dark lines appear in it, as shown in Fig. 503. These are called *Fraunhofer lines*, after Joseph Fraunhofer, a German scientist, who was one of

the first to count and describe them. The fact that the sun's spectrum is a dark-line spectrum tells us that its light comes from an incandescent solid, liquid, or gas under high pressure surrounded by an incandescent gas under relatively low pressure.

525. **Spectrum Analysis.** If any substance in the condition of an incandescent gas be examined by means of a spectroscope, Fig. 508, it is possible to determine from the nature of its spectra many facts regarding the character of the substance.

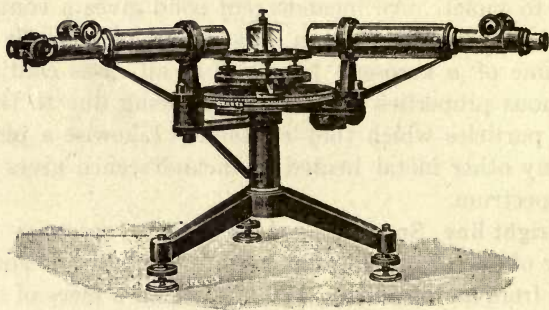


FIG. 508. — Spectroscope

For example, suppose that we wish to determine if there is any sodium in a given inorganic substance. Dip a platinum wire into the substance and then place it in the colorless part of a Bunsen flame; the salt will be volatilized, and if any sodium be present a distinct yellow color will be imparted to the flame. If this be examined by means of a *spectroscope* the presence of even the most minute trace of sodium will reveal itself by the appearance of a yellow band. Thus it is possible to determine the presence of $1/14,000,000$ gram of sodium.

Also, when the spectrum of the sun and the stars are examined and we find present the lines that are characteristic of sodium, iron, magnesium, and other metals we take for granted that these metals are present in the heavenly bodies from which the light came.

526. The Invisible Spectrum. The visible spectrum is that which is included between red and violet, about one octave of color; that is, from red making 395 trillion to violet which makes 760 trillion vibrations per second. The visible spectrum, however, is not the limit of the dispersion of ether waves which may be secured by a prism. Beyond the red is a series of longer waves which manifest themselves to our senses in the form of heat. Below the violet there are very short waves which are capable of great chemical activity. The invisible rays beyond the red are called the *infra-red*; those beyond the violet are called the *ultra-violet*.

527. Analysis and Synthesis of White Light. The white light of the sun may be considered as made up of many colors, the most striking of which are the seven so-called spectral colors which appear when white light is dispersed by a prism. The question naturally arises: Is it possible to combine these seven colors so that they may give us again white light? Sir Isaac Newton asked himself this very question and was one of the first to answer it by means of an experiment. He first passed a beam of white light through a prism, causing it to become dispersed; he then passed the dispersed beam through a second prism, inverted with respect to the first, Fig. 509, and found that the colors of the spectrum were combined by the second prism into a band of pure white light.

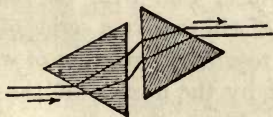


FIG. 509

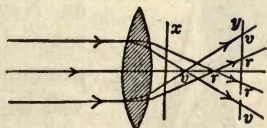


FIG. 510

The breaking up of white light into its spectral colors is called analysis of white light; the combining of these colors is called synthesis.

528. Chromatic Aberration. When white light passes through a lens two things occur: (a) it is refracted and (b) it

is to a certain extent dispersed; that is it is broken up into prismatic colors. This dispersion of white light which occurs in a lens is called *chromatic aberration* and is illustrated in Fig. 510. The violet rays, being the most refrangible, come to a focus nearer the lens than do those of the red. If, therefore, a white card be placed in the light at x there may be observed around the outer edge a fringe of red; if the card be placed at y there will be seen around the outer edge a fringe of violet. This fringe of color constitutes a very serious defect in the lens, especially where it is desired to produce a clear image, as in the case of the microscope. The *remedy for chromatic aberration* lies in the use of two lenses, one concave and the other convex, of different kinds of glass ground so as to fit closely one upon the other. In Fig. 511 there is shown an *achromatic lens* consisting of a bi-convex lens of crown glass and a plano-concave lens of flint glass. The light passing through such a lens is brought to a focus without being dispersed. Lenses of this type are used in the objective of the compound microscope.

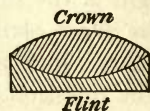


FIG. 511

529. Mixing Colors. Experiment. Since color is a sensation, it follows that the mixing of colors is nothing more than the mixing of sensations. If a color disc, sometimes known as Newton's disc, Fig. 512, be rapidly rotated, the eye will receive a series of impressions, the resultant sensation of which will be caused by the mixing of the several sensations due to the different colors on the disc. Thus if the disc be rotated the eye will no longer see yellow, blue, green, etc., but will see in their stead gray or white, or whatever the resultant color may be.

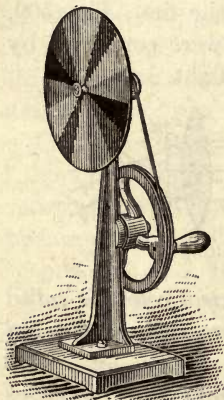


FIG. 512

530. Complementary Colors. Any two

colors which when mixed produce the sensation of white are called complementary colors. A complementary color disc is shown in Fig. 513. Those colors which are opposite each other on the disc will, on being mixed, produce white. Thus yellow and dark blue are complementary, as may be shown by the following very simple experiment. Place a yellow and a blue strip of paper a few inches apart on the table and then

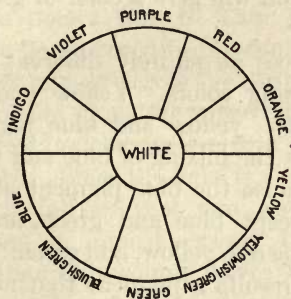


FIG. 513

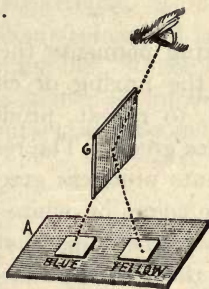


FIG. 514

view them by means of a piece of glass as shown in Fig. 514. The sensation produced, that is, the resultant color, will be neither blue nor yellow, but white. The light from the blue reaches the eye by passing through the glass; that from the yellow by reflection from the glass. Both trains of light waves thus unite and give rise to the common sensation of white.

Those colors which produce the sharpest contrast are in general complementary to each other. For example, red and green are complementary colors. When these colors are brought near together the red appears redder and the green greener. Thus the red rose appears redder when seen against the background of green leaves than it otherwise would. Blue also appears bluer when placed adjacent to a yellow field.

531. Mixing Pigments. Experiment. We have just learned that when the colors (sensations) blue and yellow are mixed they produce white. Now, however, if yellow and blue pig-

ments be mixed, in the sense in which the painter mixes colors, the resulting color will not be white, but green. This can easily be shown by mixing yellow and blue pigments from a set of water colors.

The effect of mixing pigments can also be shown by making on the blackboard with a blue crayon a broad band of blue; then over the blue make a corresponding band of yellow. The mixture of blue and yellow crayon will give a color of greenish tinge.

Mixing pigments then produces an entirely different effect from the mixing of corresponding colors. Yellow and blue colors, to repeat, produce white; yellow and blue pigments produce green. The reason that the mixing of blue and yellow pigments produces green is because the blue pigment absorbs all the colors of white light except blue and green, and the yellow pigment absorbs all but the red, yellow, and green. Now when the two are mixed there results a pigment that absorbs every color but green, which is reflected. In a similar manner we may explain the resulting color due to mixing any number of pigments. If, for example, we should take a combination of pigments of such a nature that the mixture would absorb all the colors of white light, the resulting mixture would be black.

532. The Color of Bodies. The color of any body is due to the character of the light which it reflects, or transmits. If it reflects light having a wave length of about 0.0007 millimeter it gives rise to the color of red, and so on throughout the color scale. We often speak of an object as being painted a given color, as, for example, red. What is really done is to put upon the object a pigment which has the property of absorbing the light of all colors excepting red, or green, or whatever the color may be. Also, if a piece of glass be held up before the sunlight, and the light which passes through it falls upon the eye and we receive the impression of red, we say that the glass is red. It is red simply because it has the property of absorbing all the colors except those which give rise to the sensation of red, which wave

length it transmits. That is, the glass absorbs all other waves and transmits only those that produce red.

This all means that the color of any object is not something that resides within the object, but is a sensation having its seat within the brain of the observer. The red of the rose, for example, is not in the rose, but in the sensorium of the observer. The rose simply has the property of reflecting those waves which give rise to the sensation of red.

533. Colors Due to Thin Films. Experiment. If a soap bubble be observed in the sunlight, brilliant colors will be seen shifting rapidly across the surface of the bubble. These colors, due to thin films, are caused by what is known as *interference*. This can best be explained in an elementary way by means of Fig. 515. Since the light is a wave motion, it follows that two waves may interfere in almost exactly the same way that two sound waves interfere. It is possible, therefore, that two light waves may be superimposed one upon the other in such a way that one may exactly neutralize the other. If the light be white light, that is, light consisting of the seven prismatic colors, and one color be cut out, due to interference, then the remaining colors of the spectrum will appear. Consider a band of light, ab , as falling upon a thin film, AB . Part of this light is reflected and part passes through to the second face of the film and is then reflected. Now if it happens that a part of the wave train a which emerges at c should unite with the reflected part of b in opposite phase, then interference will occur.

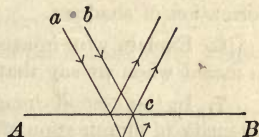


FIG. 515

This, in general, is the explanation of the brilliant bands of color which occur in the case of a soap film. The shifting of these bands is due to the fact that the film is constantly changing its thickness. Other illustrations of interference are seen in the bright colored bands which appear when a film of oil spreads out over the surface of water; also the bright bands

which appear due to cracks in ice, or in other crystalline substances, illustrate interference effects.

EXERCISES AND PROBLEMS FOR REVIEW

1. Define light. Wherein do light waves differ from sound waves?
2. Compare (a) the velocity of light with that of sound; (b) the velocity of light in a vacuum with that in air; (c) velocity in air with that in glass.
3. It is said to take light fifty-four and one half years to travel from the North star to the earth. How far away is the North star?
4. The star Arcturus is 600,000,000,000 miles from the earth. Suppose that this star were suddenly extinguished, how long would it be before astronomers could detect the fact?
5. Make a drawing to illustrate the umbra and the penumbra in the formation of shadows.
6. Explain why images through small apertures are inverted. What is meant when we say that such images are perverted?
7. In the case of images formed through small apertures, how is the intensity of illumination affected by moving the source of light toward the aperture? How is the intensity of illumination affected by increasing the size of the aperture? What effect does this have on the distinctness of the image?
8. An image is formed by a plane mirror. What is the relation of the image to the object with respect to distance from mirror? Is the image real or virtual?
9. If a person walk toward a plane mirror with a velocity of 8 ft. per second, with what velocity does he approach his image?
10. Define and illustrate by drawing with reference to a spherical mirror the following terms: (a) Center of curvature; (b) vertex; (c) principal axis; (d) principal focus; (e) secondary axis.
11. Where must an object be placed with reference to the focus of a spherical mirror in order that the image be real and (a) larger than the object? (b) Smaller than the object?
12. In what two positions with reference to spherical mirrors may an object be placed so that the image is virtual? Make drawing to illustrate each.
13. Define and illustrate refraction. Explain how light is refracted with reference to the normal when it passes (a) from a rare to a dense medium; (b) from a dense to a rare medium.

14. A man standing on the bank of a stream wishes to spear a fish which lies in the water below him. Should he strike a little high or a little low? Illustrate by diagram.

15. Define index of refraction. What does it mean when we say that the index of refraction of water is $\frac{4}{3}$? What is the velocity of light in water?

16. Considering the index of refraction of crown glass to be 1.5, what is the velocity of light in crown glass?

17. What is a convex lens? What is its effect on parallel rays of light? Name and illustrate by drawing the three classes of convex lenses.

18. What is a concave lens? What is its effect on parallel rays of light? Name and illustrate the three classes of concave lenses.

19. Where must an object be placed with reference to the focus of a convex lens in order that the image be real and (a) smaller than the object? (b) same size as the object? (c) larger than the object?

20. Make drawing to illustrate the simple microscope.

21. Make drawing to illustrate cross section of the human eye. Name and explain the function of each part.

22. Define and illustrate visual angle. Explain the relation of the apparent size of an object to the visual angle.

23. What is spherical aberration in a lens? How may it be remedied?

24. What is chromatic aberration? How may it be remedied?

25. Define color, and name in order the colors of the solar spectrum.

26. Suppose that a person were in a balloon above the clouds, what shape of rainbow might it be possible to see?

27. The velocity of light is 300,000 km. per second, and the wave length of red light is 0.0007 mm. How many waves of light of this color will strike the eye in one second?

28. If the waves producing the sensation of red were all absorbed from sunlight, what color would objects that were formerly red appear to have?

29. (a) What is a continuous spectrum? (b) bright-line spectrum? (c) dark-line spectrum? Under what condition is each formed?

30. The luminosity of a flame of a kerosene lamp is due to incandescent particles of carbon. What sort of a spectrum will such a flame give?

31. Compare the mixing of yellow and blue colors with that of yellow and blue pigments.

32. What are complementary colors? Give some examples. How do complementary colors affect each other when placed side by side?

33. Explain the occurrence of brilliant bands of color in the soap film. What causes the shifting of the colors in the film?

34. When two pieces of glass are pressed together colored bands sometimes appear. Explain.

35. Why does a photographer use a red light in the photographic dark room?

For additional Problems and Exercises, see Supplement.

SUPPLEMENT

NOTES

534 (Art. 22). It is important to note that the International Metric Standards used for reference are not the Standards of the Archives, but are the International Standard Meter and Kilogram kept at the International Bureau, at Sèvres, near Paris. At certain times our National Metric Standards at Washington are taken to Paris and compared with the International Standards. This is done to determine that no variation in our standards, due to temperature changes or other causes, has occurred. This comparison, to repeat, is made with the International Standards kept in the International Bureau.

535 (Art. 25). The reason for defining the liter in terms of the volume of a kilogram of air-free distilled water at 4°C. , instead of defining it directly as 1000 cubic centimeters, is because of the convenience in calibrating glass flasks and similar vessels. It would not be an easy matter to determine the volume of a Florence flask, for example, by direct measurement; on the other hand, it is an easy matter to determine its volume by finding the mass of water which it will contain at a given temperature.

536 (Art. 37). Accelerated Motion of Bodies Having an Initial Velocity. In our discussion of accelerated motion in the text, we considered only the simplest cases of bodies having an accelerated motion starting from rest. If a body fall from rest its initial velocity is zero and its velocity at the end of any instant is

$$v = gt$$

If a body be thrown downward with an initial velocity v' , it will have at the end of any given interval a velocity represented by the equation

$$v = v' + gt$$

The space passed over during any interval of time will then be

$$s = v't + \frac{1}{2}gt^2$$

In general we may write

$$\begin{aligned}v &= v' \pm at \\s &= v't \pm \frac{1}{2}at^2\end{aligned}$$

EXERCISES. 1. Suppose that a sled start from rest on a hillside and move downward with an acceleration of 3 ft. per second per second. (a) What will be its velocity at the end of 10 seconds? (b) at the end of 1 minute?

2. Suppose that a ball on an incline start from rest and roll downward with an acceleration of 4 ft. per second per second. How far will it roll (a) in 20 seconds? (b) in 1 minute?

3. If the ball (problem 2) be given an initial velocity of 10 ft. per second, how far will it roll in 10 seconds?

4. Suppose that the ball be thrown up the incline with an initial velocity of 30 ft. per second. How far will it roll in 5 seconds, the acceleration being -4 ft. per second per second?

5. A body starting from rest falls for 10 seconds. Over what space will it pass (a) in feet? (b) in centimeters?

6. A body is thrown downward with an initial velocity of 10 ft. per second. How far will it go in 10 seconds?

7. A body is thrown upward with an initial velocity of 4900 cm. per second. How far will it rise in 3 seconds?

537 (Art. 42). The unit of momentum is the momentum of unit mass having unit velocity. In the C.G.S. system the unit of momentum is the momentum of a mass of one gram moving with a velocity of one centimeter per second. There is no generally accepted name for this unit, although the name *bole* was proposed by the Committee of the British Association. In the F.P.S. system the unit of momentum is the momentum of a mass of one pound having a velocity of one foot per second.

538 (Art. 45). The third law of motion expresses the fact that the action of a force operating between two bodies is dual in character; that is, the force always acts both ways. Thus, if we push on a body with a force F , the body pushes back with an equal force F' . Now force may be defined as $F = ma = \frac{mv}{t}$, in which v is the change of velocity in the time t ; as also $F' = \frac{m'v'}{t}$. The t is the same in both cases since the time in which the force acts on both bodies is equal. Now since $F = F'$, then $\frac{mv}{t} = \frac{m'v'}{t}$, and therefore $mv = m'v'$. That is, when any mutual action takes place between any two bodies the momenta generated in opposite directions are equal.

539 (Art. 49). Since the attraction of the earth (the force of gravity) varies for different places on the earth's surface, it would seem necessary to define the unit of weight with reference to some particular place. In Great Britain the weight of a pound is defined as the force with which

the earth attracts a pound mass at sea level, 45° north latitude. In this country (U. S.) no specific definition has ever been made, the English definition being generally accepted. The slight variation of a force of a pound due to the variation of gravity is, for all ordinary measurements, practically negligible.

540 (Art. 51). In gravitational units the force of a pound, for example, is the force with which the earth attracts a pound mass. Absolute units, on the other hand, are measured in terms of unit mass and unit acceleration; that is, $F = ma$. Now if a pound mass were allowed to fall freely in a vacuum, its acceleration at sea level would be about 32.16 feet per second per second, and in a like manner, a mass of one gram would have an acceleration of about 980 centimeters per second per second. We say then that the force of a pound measured in gravitational units is equivalent to about 32 absolute units (poundals), and that a force of one gram in gravitational units is equivalent to about 980 absolute units (dynes).

541 (Art. 52). In a strict scientific sense, a force is fully described when we know four things about it; namely, (a) its point of application, (b) its magnitude, (c) its direction, and (d) its sense. In ordinary language the word direction means both direction and sense. Thus a stone falls to the ground. We say in ordinary language that the direction of its motion is down. In scientific language we would describe the fall of the stone by saying that its direction is vertical and its sense down. In an elementary text, however, it is not considered necessary to introduce this additional term.

542 (Art. 58). **To Find the Resultant when more than Two Components are Given.** When more than two components are given, Fig. 516, we proceed to find the resultant as follows: First, we select any two components, as AB , AC , and complete the parallelogram $ABDC$, and draw the diagonal AD . With this line AD , and the next component AE , complete a new parallelogram $ADFE$. Continue this process until all the components have been taken. The last diagonal, which in this case is AF , represents the resultant of all the components. It makes no difference in what order the components are taken, the resultant will be the same in every case, both in direction and magnitude.

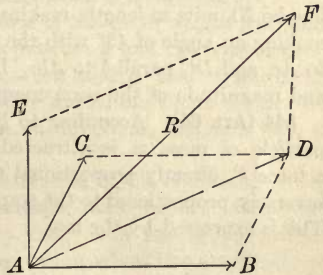


FIG. 516

543 (Art. 59). **Resolution of Forces.** In considering the subject of resolution of forces, two important cases arise, as illustrated in the following examples:

(a) Given the resultant and the magnitude and direction of one of the components to find the other. Suppose, for example, a resultant force of 100 dynes is due to two components, one of which has a magnitude of 60 dynes and makes an angle of 25° with the resultant, and we desire to find the direction and magnitude of the other component. Lay off line AB , Fig. 517, equal to 60 units in length, representing 60 dynes. Then from the point A lay off AD , the resultant, 100 units in length, making an angle of 25° with AB . Draw line BD . Now draw AC equal and parallel to BD . The line AC represents in direction and magnitude the component sought.

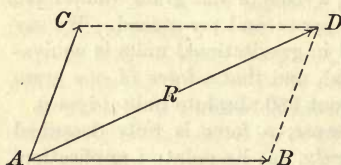


FIG. 517

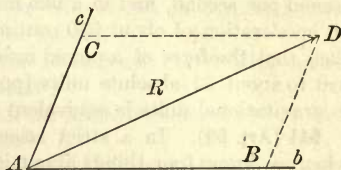


FIG. 518

(b) Given the resultant and direction of the components to find the magnitude of each. *Example.* Two component forces produce a resultant force of 20 pounds. The angle between the resultant and one of the components is 25° and the other 45° . It is desired to find the magnitude of the components. Draw line Ab , Fig. 518. From point A draw AD representing the magnitude and direction of the resultant. Let this line be 20 units in length, making an angle of 25° with Ab . Now draw Ac making an angle of 45° with the resultant AD . From D draw DB parallel to Ac , and DC parallel to Ab . Lines AB and AC represent the direction and magnitude of the components.

544 (Art. 64). According to Newton's law of universal gravitation any particle of mass m is attracted by any other particle of mass m' , with a force F , directly proportional to the product of the masses mm' , and inversely proportional to the square of the distance between the particles. This is expressed by the law

$$F = k \frac{mm'}{d^2}$$

in which k is a constant called the constant of gravitation. This constant k represents the force with which two particles, each of unit mass, attract each other when at unit distance apart. The value of k has to be determined by experiment, and its numerical value depends upon the units of measurement adopted. What can be directly observed is, of course,

not the force itself, but the acceleration which it produces. Now taking $g = 980$, we find in C.G.S. units that $k = 0.000\ 000\ 067$.

Example. The masses of two homogeneous spheres are 10 and 30 grams respectively. The distance between their centers is 30 centimeters. Find the force in dynes with which the two bodies attract each other.

Solution: $F = k \frac{mm'}{d^2} = 0.000\ 000\ 067 \times 10 \times 30/900 = 0.000\ 000\ 022$ dyne.

545 (Art. 66). According to Newton's law of gravitation the weight of a body above the surface of the earth will be inversely proportional to the square of its distance from the center of the earth. Since the mass of the earth and the mass of the body remain constant, we may say that the weight of a body at the surface is to its weight above the surface as the square of its distance from the center is to the square of the radius of the earth; that is,

$$w : w' = d'^2 : d^2$$

Example. A body weighs 100 lbs. at the surface of the earth. What will be its weight 1000 miles above the surface of the earth? *Solution:*

$$100 : x = 5000^2 : 4000^4. \text{ Hence } x = 64 \text{ lbs.}$$

If the earth were uniform in density the weight of a body below the surface would be directly proportional to its distance from the center. It is customary in elementary texts to give problems illustrating this law of variation below the surface, it being taken for granted that the earth is of uniform density. Since the density of the earth, however, increases from the surface to the center, such an assumption is not justified.

The reason why a body below the surface of the earth weighs less than at the surface is because there is less mass between it and the center of the earth to attract it. It can be shown mathematically that if the earth consisted of a hollow sphere and a ball were placed anywhere within the interior, it would be attracted equally in all directions, *that is to say, it would remain in position wherever placed.*

546 (Art. 78). In the mathematical derivation of the equation for the pendulum, $T = \pi\sqrt{l/g}$, the assumption is made that the arc swept out by the pendulum is practically a straight line. Now this is true within the limits of error permissible in this derivation when the amplitude of the arc is not over 3 degrees; that is, when the entire arc subtends an angle of 5 or 6 degrees.

547 (Art. 92). The derivation of the equation for kinetic energy $F = \frac{1}{2}mv^2$ is as follows: If a mass m be acted upon by a force F , for a time t , during which it receives an acceleration a , it will pass over a space

$$s = \frac{1}{2}at^2$$

and acquire a velocity

$$v = at$$

Now energy is numerically equal to work; hence we may write

$$W = Fs = mas = \frac{1}{2}ma^2t^2 = \frac{1}{2}mv^2$$

It will be observed that in deriving this equation for kinetic energy, we started with an equation which expressed force in absolute units, $F = ma$. It is for this reason that the equation $K.E. = \frac{1}{2}mv^2$ gives results in absolute units (foot poundals or ergs).

548 (Art. 100). In speaking of the reduction of compound machines to one of the six simple types, we use the term *mechanical* machine because, using the term machine in a broad sense, there are some machines which cannot be reduced to any one of the six simple machines. An example of this is the electric transformer. This instrument is in a sense a machine for the transformation of electrical energy of high potential, say, to low potential. It, however, cannot be called a mechanical machine.

549 (Art. 108). The word *pressure* in many texts is used as synonymous with force. When used in an accurate scientific sense, however, pressure always means force per unit area; that is, for example, force in pounds per square inch or square foot, or grams or dynes per square centimeter. In this text pressure is always used to mean force per unit area.

550 (Art. 113). By the term *center of figure*, as used in connection with the equation $F = AHD$, we mean the center of gravity (centroid) of the area of the surface pressed upon. Thus, if the surface pressed upon be a rectangle, its centroid is at the intersection of its diagonals; if the surface pressed upon be a triangle, its centroid lies at the point of intersection of its median lines; if the surface pressed upon be a circle, its centroid lies at its center, etc.

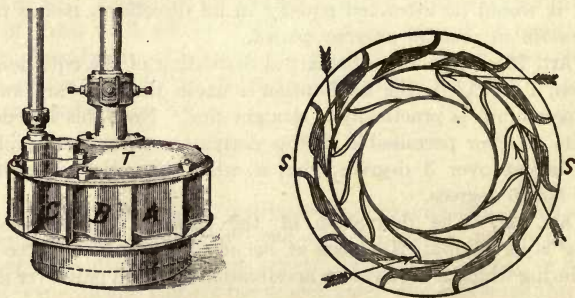


FIG. 519

551 (Art. 118). The Turbine Water Wheel. This is a type of water wheel somewhat similar in principle to that of the water motor. The wheel is placed on a vertical shaft. Water from the dam is conducted through a cylindrical tube, or flume, to a penstock, which surrounds the stationary iron case containing the turbine, *T* of Fig. 519. Water enters the turbine case through the openings marked *A*, *B*, *C*, striking against the blades of the wheel and then discharging down through the center. Accompanying Fig. 519 there is a cross sectional diagram of the wheel, illustrating the direction of the inflow of the water at *S*.

552. Hydraulic Elevator. An application of the transmission of energy by water power under pressure is found in the hydraulic elevator. There are two common types of such elevators, one of which is shown in Fig. 520. When the piston *P* is forced downward, for example, by the pressure of the water, the elevator cage rises. Since there are four ropes or cables attached to the movable pulley system, it follows that when *P* moves 1 foot the cage will move 4 feet. Thus, if *P* were to move downward 10 feet, the cage would move upward a distance of 40 feet.

Sometimes the cage is fastened directly upon a shaft which moves in a deep pit, Fig. 521. Passing through the cage is a cord which operates a two-way valve, Fig. 522. When *c* is pulled upward, valve *v* opens and *v'* closes, admitting water to the pit from the high pressure main, and thus causing the elevator to ascend; when *c* is pulled downward valve *v* is closed and *v'* is opened and the water flows from the pit into the waste pipe, allowing the elevator to descend.

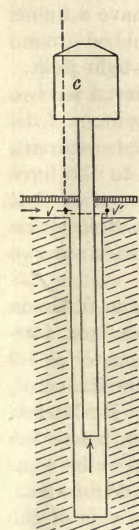


FIG. 521

The general principle of the operation of a two-way valve is illustrated in Fig. 522. As the valve is set in the figure, water flows from the elevator shaft through the pipe *B* into the waste pipe *F*. When the arm *D* is moved downward through an angle of 90°, thus rotating valve *E* in a counter-clockwise direction, the openings in the valve *E* connect the pipes *A* and *B*, thus allowing water from the high pressure main *A* to enter the elevator shaft through *B*.

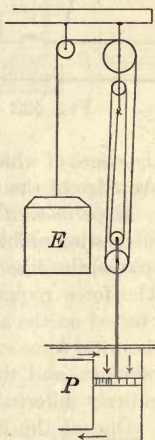


FIG. 520

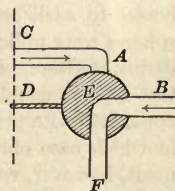


FIG. 522

553. Hydraulic Ram. The hydraulic ram is an apparatus for elevating water to a height greater than its source. The condition for the operation of the ram is that there be a supply of running water. The water flows through a pipe p and out through a valve v , Fig. 523. As the speed of the stream through the pipe increases, valve v suddenly closes, thus causing the water, because of the momentum, to force its way for an instant through the valve V into the chamber C . The water in the pipe p now rebounds, relieving the pressure on the valve v , which falls by its own weight, thus opening the orifice at the end of the pipe. The process is again repeated, and more water is forced into the chamber C . The air cushion in C tends to produce a steady flow in the vertical pipe P .

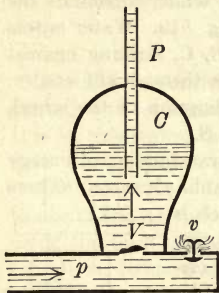


FIG. 523

554 (Art. 135, Exp. 2). In order to make this experiment work it is necessary to have a funnel the edges of which fit closely to the glass. A little vaseline rubbed around the edge of the funnel will facilitate the formation of an air-tight joint.

Experiment 3. The Magdeburg Hemispheres furnish material for two interesting problems. One is to find the total force upon the surface of the sphere, the other is to find the force required to pull the hemispheres apart. The force required to pull the hemispheres apart is equal to the force exerted on the area of a great circle of the sphere. Thus it appears that the total force exerted upon the surface of this sphere, due to atmospheric pressure, and the force required to pull the hemispheres apart are two entirely different propositions.

One of the first to experiment with these hemispheres was Otto von Guericke (1602-1686), a scientist and burgomaster of Magdeburg, Germany. Guericke prepared a pair of hemispheres having a diameter of 1.2 feet. He then thoroughly exhausted the air and invited the Emperor, Ferdinand II, to witness the pulling of the spheres apart. He hitched horses to each hemisphere, increasing the number to sixteen before the spheres were pulled apart. In this respect he played a trick upon his wondering auditors, because, as we now know well, and as he no doubt knew, the spheres could have been pulled apart by fastening one side of the apparatus to a stake or a tree and fastening the horses to the other side, in which case only eight horses would have been required. The experiment, however, would not have been so striking.

555 (Art. 148). In Fig. 524 there is shown in outline the mechanism of a metallic-valve air pump. The metallic valve fits very accurately into a groove, and is operated by the motion of the rod C , which in turn is

moved up and down by the motion of the piston *P*. This type of pump is illustrated by the usual laboratory pump.

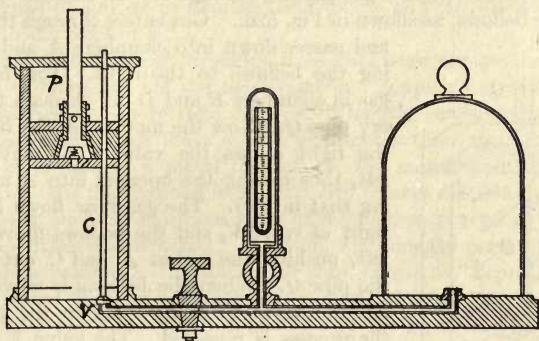


FIG. 524

556. The Automatic Air Brake. One of the most important commercial applications of compressed air is that made use of in the Westinghouse air brake, now used on nearly all steam and electric cars. The principle upon which the air brake works is illustrated in the diagram, Fig. 525. A compression pump on the engine supplies air to the receiver *R* through the pipe *P* under a pressure of about 70 pounds to the square inch. The receiver *R* connects with the cylinder *I* and with the pipe *P* through a triple valve *V*. While the pressure is on *P* the valve *V* opens in such a way that there is direct communication between *P* and *R*. When the pressure on *P* falls, due to the operation of a lever by the engineer or motorman, or by the accidental breaking of the connections, the compressed air in *R* operates the valve *V* in such a way as to shut off connections between *R* and *P* and to open connections between *R* and *I*. The brake rod *B* is then driven powerfully forward, forcing the brake against the wheels. When the pressure is again turned on in *P*, valve *V* opens in such a way as to allow the air in *I* to escape, and the spring then drives the piston to the right, thus pulling the brake from the wheels.

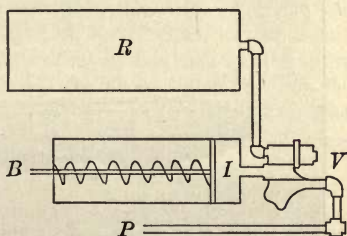


FIG. 525

The Gas Meter. The gas meter is a device which operates under the pressure of the gas in the city mains, and thus registers automatically in cubic feet the quantity of gas passing through it. It consists essentially of a double bellows, as shown in Fig. 526. Gas enters through the pipe *P*

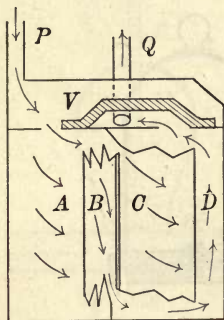


FIG. 526

and passes down into chambers *A* and *C*, pushing the bellows to the right. This forces the gas in chambers *B* and *D* out through the delivery pipe *Q*. Now the motion of the bellows to the right causes the valve *V* to move to the left, thus closing the opening into *A* and opening that into *D*. The gas now flows in on the right of valve *V*, and the bellows moves to the left, pushing the air in *A* and *C* out through the pipe *Q*. When the bellows is moved to the left the valve *V* again slides to the right and the process is repeated. The valve *V* connects not only with the bellows, but also with a train of wheels which register on a set of dials the number of cubic feet of gas consumed.

557. The Dirigible Balloon. A dirigible balloon consists, in general, of a cigar-shaped receptacle for holding the gas, below which is suspended

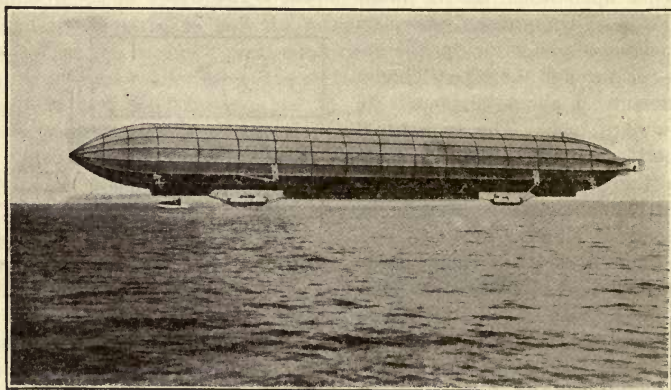


FIG. 527. — Zeppelin Dirigible Balloon

the car for the accommodation of the driving engine and passengers, Fig. 527. Propulsion is obtained by means of the rotation of fan-like propellers. On the dirigible shown in Fig. 527 there are four propellers arranged in

pairs, one pair being placed above each car. These balloons are usually supplied with two sets of rudders operating at right angles to each other, one designed to elevate or depress the balloon, and the other designed to move it to the right or left.

Of the various types of dirigibles those that were constructed by Count Zeppelin of Germany are the most famous. Zeppelin's air ship consisted of a cylindrical sac more than 300 feet in length, containing as many as 17 compartments, each filled with a gas lighter than air. Rigidity was secured by means of a metal framework, the metal used being mainly aluminum. His first balloon had a capacity of over 400,000 feet. As can be imagined, such an enormous piece of mechanism proved unwieldy, and after a few trials was wrecked. Zeppelin, with dogged perseverance, built five different balloons. In 1909 his air ship, known as "Zeppelin No. IV," made a record flight of 1100 kilometers (684 miles) in thirty-eight hours. This balloon was destroyed in a storm, and the same fate befell his fifth attempt in 1910.

The main outcome of Zeppelin's experiments has been to prove the impracticability of the dirigible balloon of the rigid type. If the dirigible balloon is, in the future, to be of any use to man, it will undoubtedly be of the so-called "supple" type.

558. The Aeroplane. Aviation is the art of lifting and propelling through the atmosphere a body "heavier than air" by utilizing the resistance offered by the air itself to the movement of the body. For centuries man has attempted to emulate the flight of birds, which are in a sense heavier-than-air machines. The apparatus that he has used in attempting to fly may be classified under three heads: (a) Those which are propelled by flapping wings, in imitation of birds; (b) those which depend for their propulsion through the air upon screw-propellers alone; and (c) those which depend for their support upon wing-like surfaces, and for their horizontal motion upon the screw-propeller.

The soaring bird and the flying kite were the natural forerunners of the modern aeroplane. The operation of the aeroplane may be best understood by considering the phenomena of the flying of a kite, Fig. 528. Three forces act upon the kite. One is its weight downward; another is the force c in the cord which keeps it in an oblique position; and the third is the force of the wind, a component of which acts upward upon it. Now the aeroplane may be regarded as a kite which is self-propelling. As it is driven through the atmosphere by means of the

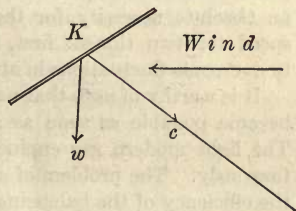


FIG. 528

rotation of its screw-propeller, the air exerts a force which is sufficient to support it. Like the dirigible balloon it is directed to the right or left, up or down, by means of rudders. Fig. 529 was taken from a snap-shot photograph of a race between an aeroplane and an automobile. It is interesting to note that while the automobile shows evidence of great speed, yet the wheels appear to be stationary, the spokes showing distinctly. This is explained by the fact that the picture is the result of a snap shot, the camera giving an instantaneous view of both aeroplane and automobile.

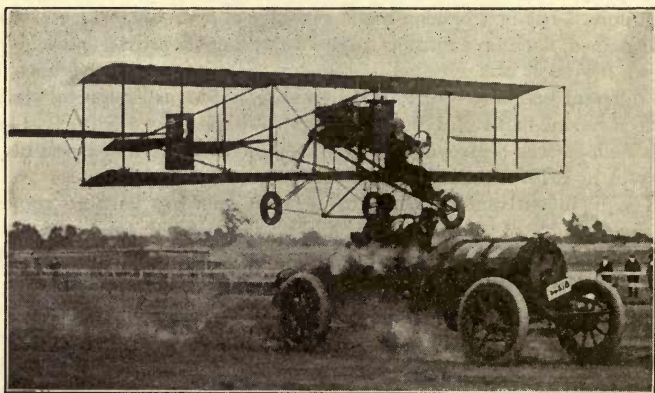


FIG. 529. — Aeroplane and Automobile Racing

In all trials in which prolonged flights have been accomplished it has been found that a speed of 30 to 50 miles per hour is required. Speed is an absolute necessity, for the heavier-than-air machine depends upon its speed for two things: first, its support in the air, and second, its ability to overcome fluctuations in atmospheric currents.

It is worthy of note that navigation of the air by means of the aeroplane became possible as soon as a light and powerful motor was developed. The light modern gas engine and the aeroplane appeared almost simultaneously. The problem of successful navigation of the air depends upon the efficiency of the balancing and propelling appliances.

559 (Art. 182). Count Rumford (Benjamin Thompson) was one of the most interesting characters of his day. He was born in Massachusetts in 1753. He went to England during the Revolutionary period, and later went to Germany, where he settled at Munich, in the employ of the Elector of Bavaria, with whom he acquired great influence. During the super-

vision of the boring of some brass cannon, he observed the relation between the work done by the horse driving the machinery and the heat developed by the boring tool. At that time it was supposed that heat was a fluid. Rumford concluded that there was some relation between the motion of the particles of the brass and the heat developed. He went so far as to measure the quantity of heat given off in the boring of one of the cannons, and in this experiment he came very near discovering the mechanical equivalent of heat.

He was shown many honors by the German government. He was made Minister of War, and on the occasion of his receiving his title, in 1790, he chose the name Rumford, after the town in New Hampshire where he had resided prior to leaving New England.

560 (Art. 192). Since mercury freezes at -39°C ., and consequently cannot be used to measure temperature below this point, liquids having lower freezing points, such as toluene, alcohol, or pentane, have to be employed. The freezing points of these liquids are: toluene, -80°C .; alcohol, -130°C .; pentane, below -200°C .

561 (Art. 211). Gay-Lussac's law is frequently referred to as the law of Charles. There is no doubt that Charles, who was a contemporary of Gay-Lussac, knew of the relation expressed by the law prior to the time of its publication by Gay-Lussac. To Gay-Lussac, however, belongs the credit of working out the law and first submitting it to publication.

562 (Art. 220). In performing this experiment a drying tube should be placed between the flask and the air pump to prevent the water vapor from the flask going over into the pump.

563 (Art. 235). A very good freezing mixture consists of a mixture of 2 parts by weight of ammonium nitrate and 1 part of ammonium chloride.

564 (Art. 239). **The Commercial Ice Machine.** The manufacture of ice depends upon the principle of the reduction of cold by evaporation and expansion. In the modern refrigerating plant, ammonia gas is condensed

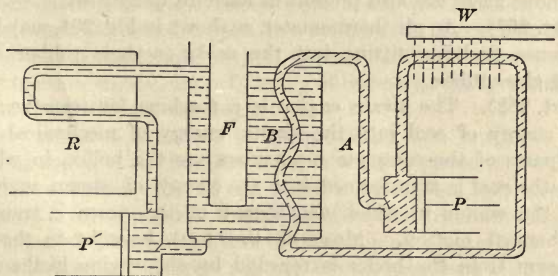


FIG. 530

into a liquid by means of a powerful pump. This liquid ammonia, which is somewhat heated by the process of compression, is cooled by a spray *W* of cold water which plays upon the pipes through which it passes. The liquid ammonia is allowed to expand in the tube *A*, Fig. 530, which is surrounded with brine, *B*. The expansion of the liquid ammonia produces intense cold, the brine thus being lowered to a temperature of -10°C . A vessel of water, *F*, placed in this tank quickly freezes. The cold brine is sometimes pumped to the various parts of the building *R*, thus supplying the low temperature necessary for cold storage.

Liquid Air. The principle of the production of liquid air does not differ materially from that involved in the production of cold as explained in the operation of the ice machine. Liquid air is now made in large quantities by a continuous process first worked out by Linde. Air is compressed in a tank under a pressure of about 200 atmospheres. It is led from the reservoir down through a coil of pipe, where it is discharged through a very small aperture. In passing through the aperture it expands and is very much cooled. It is now conducted to the top of the tank, passing on its way upward over the coils in which it was compressed. This cool air is again compressed within the coils of the reservoir, and again allowed to expand through the small aperture at the bottom. Thus after a few compressions and expansions the temperature falls more and more until it finally sinks to the point where liquefaction begins. After this stage is reached the liquid air is produced continuously, a fresh supply of air being added to the reservoir from time to time to take the place of that which is withdrawn in the form of a liquid. The boiling point of liquid air is -191°C .

565 (Art. 252). The carbon dioxide in the breath acts with the calcium hydroxide of the lime water in accordance with the following chemical reaction: $\text{CO}_2 + \text{Ca}(\text{OH})_2 = \text{CaCO}_3 + \text{H}_2\text{O}$. It is assumed that when a relatively large percentage of carbon dioxide is present in the air, other and poisonous gases are also present in harmful quantities.

566 (Art. 257). An air thermometer, as shown in Fig. 201, may be made from Florence flasks by fitting into the necks one-hole rubber stoppers containing glass tubes.

567 (Art. 262). The steam engine is a machine for transforming the potential energy of coal into the kinetic energy of mechanical motion. The two parts of the complete mechanism are the boiler, in which the energy of the coal is transformed into the energy of steam under pressure, and the engine in which the energy of the steam is transformed into mechanical motion. Most of the heat brought to the engine by the steam from the boiler is rejected by the engine in the exhaust. This loss of heat varies from 70 per cent of the heat of the steam

in the best engines, to over 90 per cent in the poorer types. In many manufacturing establishments the heat of this exhaust steam is recovered by using it for heating or manufacturing purposes. In some modern engines steam is superheated previous to its admission to the engine. This is to prevent its condensation on entering the expansion chamber. By means of the use of superheated steam the economy of a simple non-condensing engine may be made nearly equal to that of a compound condensing engine.

Steam engines are usually classified into noncondensing and condensing engines. (a) A *noncondensing engine* is one in which the exhaust steam passes directly from the cylinder to the atmosphere. In this case the piston always works against a back pressure of one atmosphere; that is, there are two forces acting on the piston when it is in motion. One is the steam tending to drive it in one direction, and the other is atmospheric pressure tending to drive it in the opposite direction. It is clear, therefore, that if the atmospheric pressure could be removed the efficiency would be increased to the extent of 14.7 pounds per square inch. (b) The *condensing engine* is one in which the exhaust steam passes into a cooling chamber, Fig. 531. This usually consists of a chamber surrounded by water and into which a spray of cold water is admitted. When the steam comes in contact with the cold spray it is condensed, producing a partial vacuum, and thus reducing the back pressure on the piston.

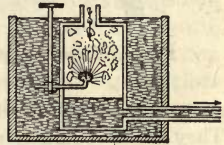


FIG. 531

Steam engines are also classified as simple and compound. (a) A *simple engine* is one in which the steam does work in a single expansion, and thus passes into the exhaust. (b) A *compound engine* is one in which the steam under high pressure enters one cylinder, does work upon the piston, then enters a second cylinder, again doing work, and so on. When the steam exerts its pressure upon two cylinders in succession, the engine is called a double-expansion engine; when it acts upon three cylinders, a triple-expansion engine, etc. In many of our ocean-going vessels engines are used of the quadruple-expansion type.

Engines are also classified as reciprocating and turbine. (a) The *reciprocating engine* is the familiar type, in which a piston moves back and forth in the cylinder. (b) In the *steam turbine*, Fig. 532, steam under high pressure is driven against the blades of a wheel, thus causing rotation. In some types of the steam turbine the steam in passing through the rotating system strikes successively against two or more sets of blades in its passage from one end of the revolving drum to the other, Fig. 533. At

the end of the drum where the steam enters, the blades are smaller than at the other end, the steam thus in moving forward expands, doing work at the expense of its own heat. Steam turbines have the advantage over

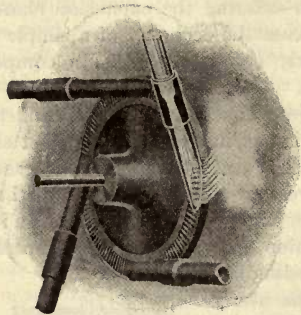


FIG. 532. — Steam Turbine

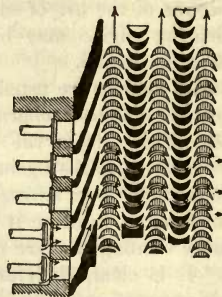


FIG. 533

reciprocating engines in that they occupy less space and run more quietly. They are used largely on steamships and in running electric generators.

568 (Art. 263). The Gas Engine. In the steam engine fuel is burned in the furnace, generating steam, which is conveyed from the boiler to the

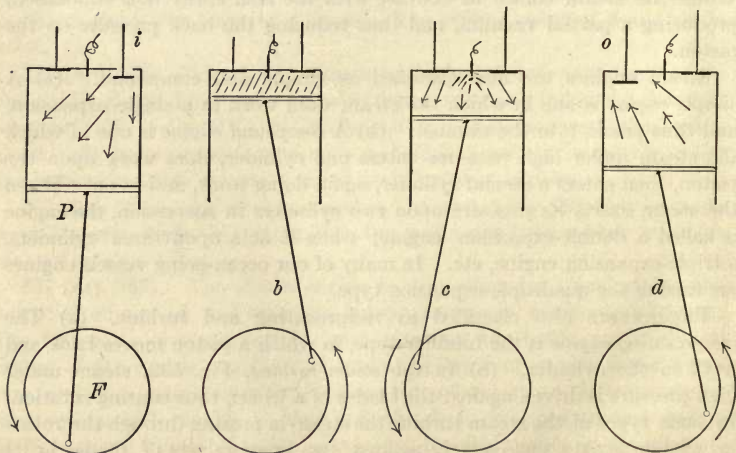


FIG. 534. — Diagram of Four-Cycle Gas Engine

engine, where expansion takes place. This involves at every step a waste of energy. In the gas engine the entire process of combustion and expansion takes place in the cylinder itself. A mixture of air and gas, or of air and gasoline, is passed into the cylinder and there exploded. This produces the pressure necessary to push the piston forward. The cylinder is supplied with two valves, an inlet and an outlet. In Fig. 534 there is represented the four steps of a four-cycle, single-cylinder gas engine. (a) First, the flywheel is turned by hand, or other device, causing the piston to move down and thus suck in a mixture of air and gas through the valve *i*. (b) As the flywheel continues its rotation, the piston moves back, compressing the gas. (c) The compressed gas now explodes, driving the piston forward. (d) On the back stroke of the piston the burnt gases are ejected through the valve *o*. To repeat, the four steps required to complete the cycle include the following: Downward stroke of piston and intake of gas; upward stroke of piston and compression of gas; explosion of gas, causing downward motion of piston; upward motion of piston and ejection of gas. The explosion of gas is due to an electric spark, which is timed to occur at the proper moment. Since the expanding gas acts on the piston during only one part of this entire operation, it is necessary in gas engines to provide a heavy flywheel, the momentum of which is sufficient to operate the piston during the remaining three steps.

The gas engine just described is called a four-cycle engine; that is, it requires four strokes of the piston to complete the cycle. An engine requiring two strokes to the cycle is called a two-cycle engine.

The efficiency of the gas engine, as measured by the number of B.T.U. per cubic foot of gas consumed, is high, 25 per cent or greater. It must be remembered in comparing engine efficiencies that the fuel used by the gas engine is more expensive than that used by the steam engine.

569. The Toepler-Holtz Machine. The Toepler-Holtz machine, Fig. 535, is provided with two glass plates of which *A*, Fig. 536, is stationary and *B* is adjusted so as to rotate. On the back of the stationary plate there are pasted two strips of tin foil *C* and *D*. These are called inductors. On

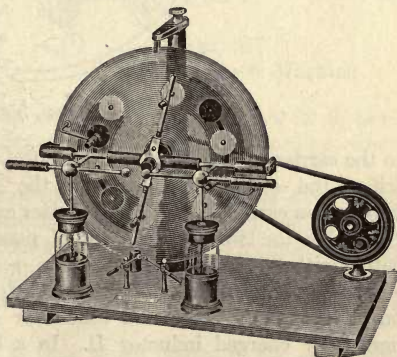


FIG. 535
Toepler-Holtz Static Machine

the rotating disc there are pasted a series of circular carriers a, a', a'', a''' , made of tin foil. Each carrier has in its center a metal button designed to serve as a contact. Passing from one inductor to the other there is a metal rod E . The conductors which approach each other at P end in metal points at M and N , and communicate also with two small Leyden jars. Let us suppose that the machine is in action. Inductors A and B become charged to a certain extent, one positively and the other negatively. Sometimes this charging is done by touching one of the inductors with an electrified body; usually, however, the initial rotation of the machine is sufficient to give the inductors a slight initial charge. Now as the disc rotates in the direction indicated, let us consider what happens

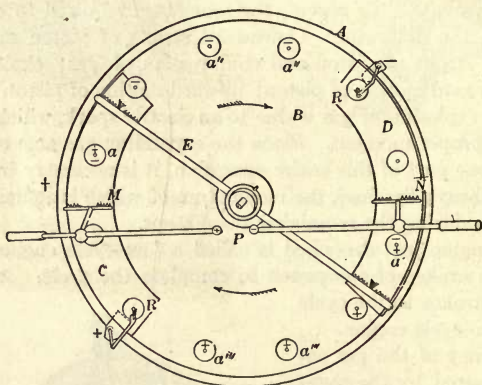


FIG. 536

to the carrier a . As it passes in front of the inductor A , it becomes electrified, the $-$ charge being bound, the $+$ charge free. The same thing happens on carrier a' , only in this latter case the $+$ is bound and the $-$ free. Now when the two carriers, a and a' , pass under the metal brush communicating with the metal rod E , the free $+$ charge on one neutralizes the free $-$ charge on the other. The carrier with its negative charge (a'') is carried on to the metal brush and conductor R . It is here transferred to the negatively charged inductor D . In a like manner the carrier with its positive charge (a''') is carried to the conductor R' , and thence to inductor C . Thus every rotation of the disc tends to charge the inductors C and D to a high potential, C with a $+$ charge and D with a $-$ charge. When these inductors become highly charged, a discharge takes place between the inductors and the metal points M and N , which communicate with the

Leyden jars. When the charge on the Leyden jars becomes sufficiently great a discharge takes place across the gap at *P*. Thus it appears that the action of the machine is, in general, similar to that of the electrophorus.

570. The Wimshurst Machine. The essential difference between the Wimshurst and the Toepler-Holtz machine is that the Wimshurst, Fig. 537, has two plates revolving in opposite directions. These plates carry a large number of tin foil strips which act alternately as inductors and as carriers. This does away with the necessity of separate inductors, as in the case of the Holtz machine. The action of the machine may be explained briefly as follows: Only the slightest difference of potential is necessary to start the induction. Consider that the sectors near *A* on the rear plate have a slight + charge. This will induce a - charge on the front rotating plate, which communicates with the brush on the rod *CD*. The free + charge will be repelled along *CD* to *D*. The sector at *A*, having thus been charged by induction, moves on to the discharging rods at *E*, charging the Leyden jar *L*. In a similar manner the sector at *B*, having received by induction a + charge, moves on to the discharging conductor at *F*, charging *L'*.

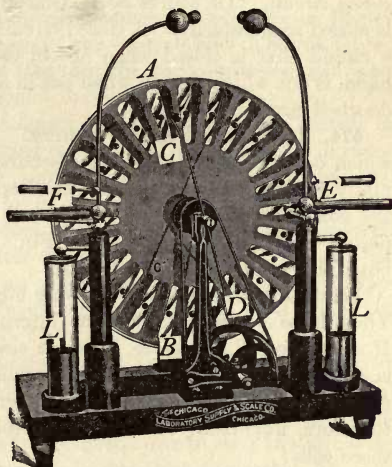


FIG. 537
Wimshurst Static Machine

571 (Art. 302). Small drops of moisture or particles of dust on electrical apparatus designed for use in electrostatics serve as discharging points. In order, therefore, to perform experiments with the electroscope, electric machine, or similar instruments, it is necessary that the apparatus be free from dust and that the experiments be performed when the air is dry.

572 (Art. 313). Polarization is that which occurs in the cell tending to reduce its E.M.F. Polarization may be due to (a) a change in concentration of the electrolyte or (b) to a collection of gas, as hydrogen for example, on the positive electrode. The reason that hydrogen reduces the E.M.F. of the cell is mainly due to the fact that this element (H) acts toward zinc like a metal, the E.M.F. of the combination *H-Zn* opposing

the E.M.F. of the *Zn-Cu* electrodes, and thus diminishing the electromotive force of the cell.

573 (Art. 317). By "closed circuit work" we mean work similar to that in connection with the telegraph system. When the operator is through sending his message he closes his switch or key, and the current flows around the circuit until the next message is sent; hence the name *closed circuit*. Of course every time the key is pressed down the circuit is closed momentarily. A closed circuit then, as used in this sense, means a circuit that is closed when not in use. An open circuit, on the other hand, is one which is open when not in use, as is illustrated by the ordinary doorbell circuit.

574. The Lead Storage Battery. The complete chemical reactions which occur in the charge and discharge of storage batteries are not definitely known. In the case of the lead cell, however, we may represent the condition of the plates of the cell when charged as follows: Positive plate = PbO_2 ; negative plate = Pb . On discharge there is formed on both plates lead sulphate, PbSO_4 .

Lead storage cells have relatively high E.M.F., 2.1 volts when charged. They have an exceedingly low internal resistance, less than 0.1 ohm. If a storage cell, therefore, be short circuited, the current through the cell is excessively high. The lead storage battery is a very efficient and useful piece of apparatus. It is also an expensive piece of apparatus, and it is, therefore, important to observe the following cautions with reference to these cells:

(a) The lead cell should never be short circuited. A cell, for example, in which the E.M.F. is 2 volts and the internal resistance 0.02 of an ohm would furnish on short circuit a current of 100 amperes, which would be ruinous to the cell.

(b) The cell should not be overcharged. Overcharging causes overheating, which causes the plates to bend or "buckle," thus crowding the lead peroxide out of the "grids" or holes in the plate.

(c) The cell should not be over-discharged, that is, discharged below an E.M.F. of 1.8 volts. Over-discharge causes an excessive formation of lead sulphate on the plates, which permanently impairs their efficiency.

(d) Only distilled water should be used in making up the sulphuric acid solution used as the electrolyte. Impurities in the electrolyte are fatal to the life of the cell.

575. The Edison Storage Battery. The Edison storage cell has recently been put upon the market. Less is known of the chemical reactions occurring in this cell than in that of the lead cell. The positive electrode of the Edison cell consists of a nickel plate, the negative electrode of an iron plate. The electrolyte is a 21 per cent solution of potassium hydroxide,

KOH, in pure distilled water. On charge the nickel plate is oxidized to NiO_2 . On discharge the nickel is reduced to Ni_2O_3 and the iron is oxidized to FeO .

The E.M.F. of an Edison cell is 1.2 volts. Its capacity is 16.8 watt hours per pound; that of a lead cell, 8.5 watt hours per pound. It is said that an Edison cell is not injured by short circuiting. The "life" of these cells under commercial conditions is as yet undetermined.

576 (Art. 348). Manganin is a metal consisting of an alloy of 12 per cent manganese, 84 per cent copper, and 4 per cent nickel. The reason for its use in resistance coils lies in the fact that its change of resistance with change of temperature is almost zero.

577 (Art. 362). We sometimes connect the cells of a storage battery in parallel, not for the purpose of reducing the internal resistance, but in order to permit of a larger current being drawn from it with safety to the cells. This is due to the fact that the current capacity of a storage cell depends upon the area of the plate. Therefore, the greater the plate area (secured by connecting in parallel) the greater the current capacity of the system.

578 (Art. 368). The carbon in an arc lamp may be adjusted by three methods: (a) By hand; (b) by a clock-work device; (c) by a system of electromagnets.

In the arc lamp used in the ordinary laboratory lantern the adjustment of the carbons is made by hand, by means of a set of thumb screws. In the commercial arc light a set of electromagnets are operated in such a way that when the arc is broken and the current dies to zero, the armature of the electromagnet falls, allowing the carbon tips to touch. As soon as the circuit is thus completed the electromagnet attracts the armature, thus drawing the carbons apart and forming the arc.

579 (Art. 396). A diagram of a more complete line and local telegraph system is shown in Fig. 538. Two stations are represented, one at *H* and

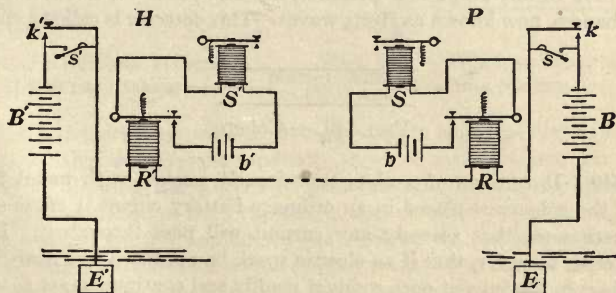


FIG. 538. — Diagram of Telegraph System

one at *P*. When the resistance of the line is very high, the current is sometimes too weak to operate the sounder. To overcome this difficulty a local circuit consisting of the sounder and local battery is connected to the main circuit by means of a relay, Fig. 539. The relay resembles the

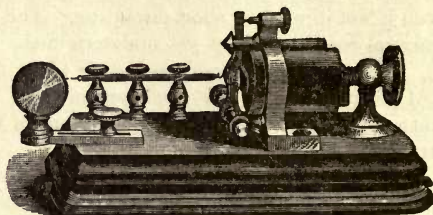


FIG. 539. — Telegraph Relay

sounder in form. It consists of an electromagnet of many turns of fine wire and is designed to be operated by very weak currents. As the armature of the relay moves back and forth in response to the line current, it opens and closes the local switch, thus causing the local battery to operate the sounder.

580 (Art. 409). Wireless Telegraphy. When the spark passes between the knobs of an induction coil or an electric machine, a violent rush of electricity occurs, which may be accompanied by electrical oscillations in any conductors connected with them. This electric surging gives rise to an electric disturbance which spreads out through space. The existence of such a disturbance was demonstrated by the brilliant experiments of Hertz. Now when this electric disturbance reaches a distant conductor it causes a somewhat corresponding disturbance in the conductor.

In 1890 Branly and Lodge prepared a delicate detector for these electric disturbances, now known as Hertz waves. This detector is called a coherer,



FIG. 540. — Coherer

Fig. 540. It consists of a glass tube loosely packed with metal filings. When the coherer is placed in an ordinary battery circuit it offers such a high resistance that scarcely any current will pass through it. It was discovered, however, that if an electric spark be produced in a near-by coil the filings in the tube at once conduct readily and continue to act as a good conductor until the tube is disturbed by tapping. The Italian physicist,

Marconi, seized upon this discovery and after much experimentation devised an apparatus which would respond to the Hertz waves over a distance of hundreds of miles.

In the modern commercial wireless telegraph there are several different types of detectors in use. They may be classified as follows: (a) Coherers; (b) magnetic detectors; (c) thermal detectors; (d) crystal detectors; (e) electrolytic detectors, and (f) vacuum detectors.

The coherer has practically gone out of use in commercial work. Some form of the crystal rectifier is now generally employed as a detector. It would be difficult at this time, however, to predict just which one of the various types of detectors will ultimately prove to be the most satisfactory.

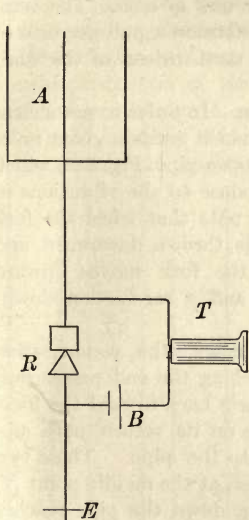


FIG. 541. — Wireless Telegraph Receiving Station

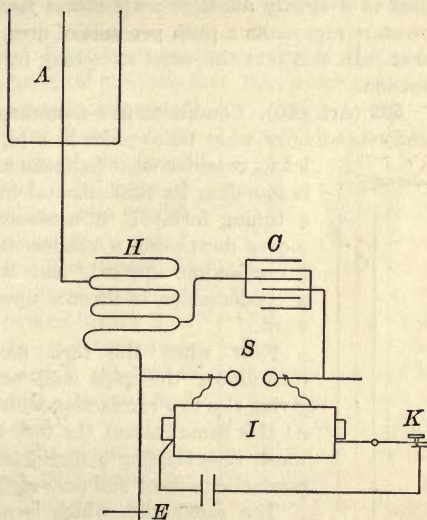


FIG. 542. — Wireless Telegraph Sending Station

In Fig. 541 there is shown a receiving system in which a crystal rectifier *R* is used. Certain crystals, especially those of carborundum, have the property of allowing the current to pass through them in one direction only. The resistance of such crystals is also modified by oscillatory discharges. When electric oscillations are received by the antennae *A*, or receiving wire, the resistance at the contact point of the crystal appears to be changed, allowing a slight current from the battery to flow through the telephone, and thus giving rise to a crackling sound.

A sending station is represented in Fig. 542. The sending antennae are represented by *A*. *H* is a helix which gives rise to self-induction, the adjustment of which, together with that of the capacity of the condenser *C*, enables the instrument to be tuned for long-distance transmission. *I* is an induction coil which is operated by means of the key *K*. *S* represents the spark-gap. When the key is operated, a series of brilliant discharges occur at *S*, giving rise to a series of oscillatory impulses which are communicated to the surrounding space. These electrical impulses are caught by the receiving antennae and the message read by means of the telephone.

581 (Art. 454). It is quite common to speak of the *tension* on a string when referring to the stretching force applied to it. *The word tension when used in a strictly scientific sense means force per unit of area.* The term pressure represents a push per unit of area, and tension a pull per unit of area. In this text the word stretching force is used instead of the word tension.

582 (Art. 460). Conditions in a Sounding Pipe. In order to get a clear understanding of what takes place in a pipe when it emits a given note,



let us consider what happens in an open pipe, Fig. 543, which is sounding its fundamental in response to the vibrations of a tuning fork. It is necessary to note that when the fork moves downward, a condensation is thrown downward and a rarefaction upward, and when the fork moves upward a condensation is thrown upward and a rarefaction downward.

Now when the fork moves down, the condensation runs down the pipe and on reaching the end passes out, giving rise to a rarefaction which starts back toward the fork. At this same instant the fork starts on its return path upward, thus sending a rarefaction into the pipe. These two rarefactions meet and pass each other, at the middle point *N*.

The rarefaction which is moving down the pipe reaches the end and passes out, giving rise to a condensation which starts upward. At the same instant the fork moves downward, sending a condensation into the pipe. These two condensations meet and pass at the middle, thus forming, for an instant, a double condensation. At the instant of the formation of a double condensation the pressure is greater than an atmosphere, and at the instant of the formation of a double rarefaction it is less than an atmosphere. This point of the meeting of condensation with condensation, and rarefaction with rarefaction, is called a node.

583. Nodes and Antinodes in Pipes. A node *N* in a pipe is the point of least motion and greatest change of pressure. In this latter respect a

node in a pipe differs in a very marked way from a node in a string. As we have seen, the change of pressure at the node is due to the appearance of, first, a double condensation, and then a double rarefaction at that point, giving rise to a maximum change of pressure. This can be shown by making an opening in the pipe at N and placing over the same a thin membrane. When the double condensation occurs at N the membrane will be forced outward; when the double rarefaction occurs the membrane will be forced inward. Thus the passage of the condensations and rarefactions along the pipes will give rise to a fluttering of the membrane at the node.

To summarize then, a node in a pipe is the point of least motion and greatest change of pressure; an antinode is the point of greatest motion and least change of pressure.

584. Nodes in Open Pipes. Fig. 544 shows the position of the nodes in the production of the fundamental and the first two overtones of an open pipe. In pipe A , sounding its fundamental, the node is at the center and the length of the pipe is one-half the wave length of the sound emitted. In pipe B

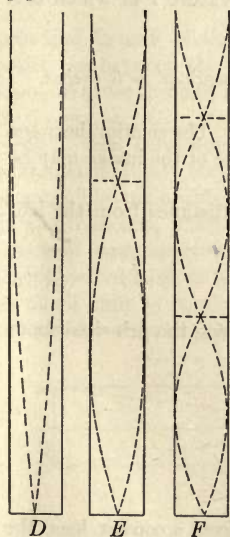


FIG. 545

there are two nodes, hence the pipe is sounding its first overtone; that is, it gives a pitch one octave higher than A . In pipe C there are three nodes; the pipe is sounding its second overtone.

In open pipes there is always an antinode at each end and one or more nodes within the pipe. Also, open pipes are capable of sounding in addition to their fundamental tone their

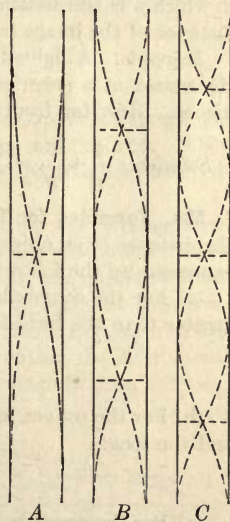


FIG. 544

first, second, third, fourth, fifth, etc., overtones.

585. Nodes in Closed Pipes. Pipe D , Fig. 545, represents a closed pipe sounding its fundamental; E represents the same pipe giving its first overtone, the vibration rate of which is three times that of the fundamental; F is sounding the next overtone, which is five times the vibration

rate of D . Closed pipes are capable of giving only the first, third, fifth, etc., overtones.

586. The *old standard of candle power* was the light furnished by a sperm candle burning at the rate of 120 grains per hour. The *modern standard candle unit* is the light equal in intensity to 1.136 hefner units. A *hefner unit* is the intensity of a horizontal beam of light from a Hefner lamp, so named in honor of its inventor. The Hefner lamp burns pure amyl acetate, under definitely prescribed conditions of wick and flame adjustment.

587. Formula for Images Formed in Spherical Mirrors. The relation between the position of the image and the object with reference to spherical mirrors is written

$$\frac{1}{p} + \frac{1}{p'} = \frac{2}{r}$$

in which p is the distance of the object from the vertex of the mirror, p' the distance of the image from the mirror, and r the radius of the mirror.

Example. A lighted candle is placed at a distance of 20 inches from the vertex of a spherical mirror, the radius of curvature r of which is 8 inches. How far from the mirror is the image?

Solution: $\frac{1}{p} + \frac{1}{p'} = \frac{2}{r}$; therefore $\frac{1}{20} + \frac{1}{p'} = \frac{2}{8}$; hence $p' = 5$ inches.

588. Formulae for Images Formed by Lenses. The relation between the distance of an object from a lens and the distance of the image may be expressed by the following equations:

(a) For the convex lens when the object is at a distance from the lens greater than the focal length:

$$\frac{1}{q} + \frac{1}{p} = \frac{1}{f}$$

(b) For the convex lens when the object lies between the principal focus and the lens:

$$\frac{1}{q} - \frac{1}{p} = -\frac{1}{f}$$

(c) For the concave lens:

$$\frac{1}{q} - \frac{1}{p} = \frac{1}{f}$$

Example. An object is placed 30 centimeters from a convex lens, the focal length of which is 10 centimeters. Find the position of the image.

Solution: $\frac{1}{q} + \frac{1}{p} = \frac{1}{f}$; therefore, $\frac{1}{q} + \frac{1}{30} = \frac{1}{10}$; hence $q = 15$ centimeters.

589 (Art. 498). The index of refraction may also be defined, and indeed is commonly defined, as the ratio of the sine of the angle of incidence to the sine of the angle of refraction. This assumes of course that the student knows the meaning of the terms sine and cosine as defined in trigonometry.

590. The Compound Microscope. This is an instrument which is designed to give a highly magnified image of very small objects. It consists of two lenses or sets of lenses, E called the eyepiece and O called the objective, Fig. 546. The object to be examined, AB , is placed beyond the

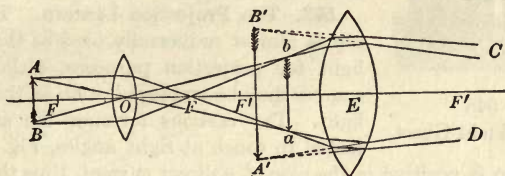


FIG. 546

principal focus F of the objective. This gives a real, inverted image ab , which lies between the principal focus of the eyepiece and the lens. This image ab gives through E a virtual magnified image $A'B'$, which is observed by the eye at DC .

591. The Telescope. In the case of the telescope the arrangement of the lenses is not very much different from that of the compound microscope. The main difference is in the relative sizes for the objective lens. In the telescope, which is designed to view distant objects, the objective lens is of large aperture and longer focal length. The reason for making the objective large is for the purpose of collecting within the instrument as much light as possible, so as to permit of large magnification without too great loss in brightness.

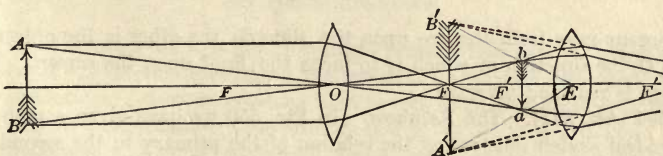


FIG. 547

The relative position of the lenses and the formation of the virtual image $A'B'$ is shown in Fig. 547.

592. The Binocular Glass. The binocular field glass, Fig. 548, is

short, compact, and has a system of lenses for each eye. The arrangement of the objective and the eyepiece are practically the same as in the astronomical telescope, but the necessary distance between them is obtained



FIG. 548
Binocular Field Glass

by having the light travel the length of the tube three times in passing from the objective to the eyepiece. This is accomplished by reflection by means of a system of prisms within the tube of the instrument. This reflection of the light within the instrument not only shortens the tube, but also causes the image to appear erect.

593. The Projection Lantern. The electric arc is almost universally used as the source of light for projection purposes, although other sources may be employed, such as the acetylene light. The carbons forming the arc are adjusted to touch at right angles, Fig. 549. The upper carbon is positive in the case of a direct current, thus throwing the brilliant light from the crater directly upon the screen.

The projection device consists essentially of two optical systems, one called the condenser, lens *C*, the function of which is to condense the

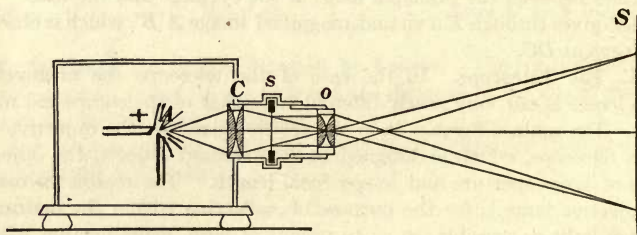


FIG. 549

divergent rays from the arc upon the slide *S*; the other is the objective lens *O*, the function of which is to focus the light upon the screen. The image is real and inverted.

594 (Art. 521). The Rainbow. In Fig. 550 we have given a more or less ideal sketch illustrating the relation of the primary to the secondary bow with reference to the number of reflections and refractions in each. The margin of each bow is selected for illustration. In order to see both bows, the eye *E* must be in such a position with respect to the sun *S* that the light refracted and dispersed by the drops will make a definite angle with the line of direction of the sun's rays. This angle depends upon the

index of refraction of the drop and the color seen by the eye. This angle varies from color to color since the index of refraction of the different colors of the spectrum vary. The angle REC for red of the primary bow is 42° , that of violet, VEC , 40° ; for the secondary bow the angles are, for violet 54° , for red 51° . The reason that the rainbow is circular, then, is that the color from only those drops which make a definite angle with EC are seen by the eye. In other words, the eye is at the vertex of a cone, a portion of the base of which is a circle forming the rainbow.

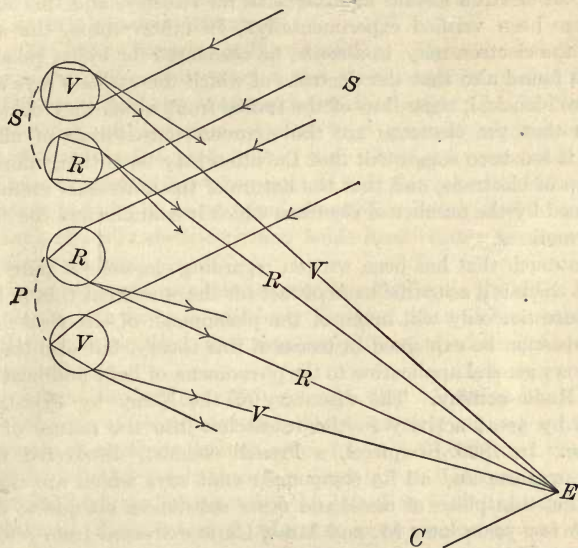


FIG. 550. — Diagram showing Formation of Primary and Secondary Rainbows

It will be observed that light forming a primary bow suffers two refractions and one internal reflection; the secondary bow, two refractions and two reflections. Now since some light is lost at each reflecting surface, it is easy to understand why the primary bow is the brighter of the two.

Theoretically, several secondary bows are possible, and with very bright sunlight three are occasionally seen. As a rule, however, only the primary and a portion of the secondary are visible. It is well to note in this connection that the phenomenon of the rainbow is much more complex than this simple discussion might imply. Sometimes "spurious" bows are seen on the inner edge of the primary. These have formed the subject of

much recent investigation, which leads to the supposition that they are due to interference phenomena.

595. The Electron Theory. Investigations of the nature of the cathode rays have led to what is now known as the electron theory of matter. The cathode rays are made up of tiny particles called electrons. These electrons, or corpuscles as they are sometimes called, are negative charges of electricity. Whether they have mass in the sense that ponderable matter has is not definitely known. It has been calculated that the apparent mass of an electron should increase with its velocity, and this surprising result has been verified experimentally. In other words, the apparent mass of the electron may, in a sense, be accounted for by its velocity. It has been found also that the electrons of which the cathode rays are composed are identical, regardless of the source from which they come. This suggests that the electrons are the common constituents of all atoms. Indeed, it has been suggested, that the atom may be nothing more than a collection of electrons, and that the nature of the individual atom may be determined by the number of electrons which it contains and the character of their motions.

While much that has been written regarding electrons is pure speculation, yet there is a scientific basis of fact for the statement that in the very near future not only will much of the phenomena of electrical discharge and conduction be explained in terms of this theory, but also that it will have a very general application to the phenomena of light and heat as well.

596. Radio-activity. The discovery of the X-ray by Roentgen was followed by great activity in the researches into the nature of electric discharge. In 1896 Becquerel, a French chemist, discovered that the element uranium and all its compounds emit rays which are capable of penetrating thin plates of metal and other substances opaque to ordinary light. A few years later M. and Mme. Curie extracted from pitch-blend a substance which they called radium, and which is many thousand times more radio-active than uranium. Radium possesses the startling property of maintaining its temperature several degrees above that of the air and of radiating heat energy without any apparent supply being imparted to it. The rays emitted by radium are of three kinds: (a) α -rays (alpha rays), which are positively charged and have a very low power of penetrating solids; (b) β -rays (beta rays), which are negatively charged and are more penetrating than the α -rays; (c) γ -rays (gamma rays), which have some of the properties of X-rays, and which have great penetrating power.

Further investigations add to the conclusion that uranium when left to itself undergoes a change which consists in the formation of other substances. One of the products of the disintegration of uranium appears

to be radium, which in turn disintegrates into still other substances. A complete series of the products of radium, which is itself probably a disintegration product of uranium, has been worked out by the English scientist Rutherford.

The facts upon which the theory of radio-activity is based seem to lead to the conclusion that in the disintegration of uranium to radium, and from radium to other elements, we have a transformation of one element into another element. We can, therefore, no longer use the old definition of an element; namely, that an element is a substance that cannot be broken up into another substance.

597 (Art. 285). Theories of Electrification. There are several theories relative to the nature and cause of the phenomenon known as electrification. The *two-fluid theory* assumes the existence of two kinds of electricity, called positive and negative. It has been generally agreed to call the electric charge found on glass rubbed with silk positive, and that found on sealing wax or hard rubber when rubbed with flannel or cat's fur negative. This theory permits of an easy and simple description of the fundamental phenomena of static electricity, and lends itself readily to the solution of elementary problems.

The *one-fluid theory* was first proposed by Benjamin Franklin. According to this view a body is positively charged when it has more than its share of the electric fluid, and negatively charged when it has less than its normal share.

The electron theory (Art. 595) assumes that electrons are elementary negative charges of electricity, and that an electric current is mainly due to a transfer of electrons through a conductor. The electron theory, combined with the ether-strain theory of Faraday and Maxwell, conceives of an electrified body as having tubes of induction radiating out from it in all directions. These tubes of induction are supposed to extend from a positively charged body to a negatively charged one. The phenomena of attraction may thus be explained, in a manner somewhat similar to that given in magnetism, by assuming that these tubes always tend to shorten, and also that they exert a lateral pressure upon each other.

None of the theories offered in explanation of electrical phenomena are entirely satisfactory. They all, no doubt, possess some elements of truth. The electron theory, when thoroughly worked out, will undoubtedly get us well along the road to a more complete understanding of many electrical manifestations which are now inexplicable.

598 (Arts. 255, 469). Radiation. — The spread of a disturbance radially from a source is called radiation. The fundamental point to be kept in mind in connection with a study of radiation is that there is a transmission of energy outward from a center through some sort of a medium.

While in a general sense the transmission of sound waves through air is a phenomenon of radiation, yet the term is now usually restricted to ether radiations. Radiant energy may give rise to electrical, optical, chemical, or thermal phenomena.

The question at once arises as to the nature of the medium by means of which this radiant energy is transmitted. This medium is called the ether. We do not know positively that such a medium really exists; we only assume that it exists. We cannot, then, speak with any degree of definiteness of its properties; indeed the properties of the ether are as much a question of dispute today as they were in the days of Newton. While, then, it is convenient and even necessary to assume that there is some such medium by means of which radiant energy may be transmitted, we should nevertheless be very careful not to allow our assumptions to come to be regarded as facts. In this text, therefore, we speak of the ether merely as a medium capable of transmitting energy, without specifying whether this transmission is due to the elastic properties of the medium, to strain tubes, or to any other specific means whatsoever.

It may not be out of place here to mention that there are today a number of theories relative to the ether which attempt to explain all the phenomena of the transmission of radiant energy. One of the most modern is that known as the *electron theory of radiation*. This theory, briefly stated, assumes that the disturbances propagated through the medium, as light from the sun for example, are due to electric disturbances in the source. Atoms may be considered as made up, in part at least, of electrons. It is assumed that the vibrations of the electrons of the source of radiant energy produce electromagnetic disturbances in the ether; they thus serve as centers of electromagnetic radiation. This theory, in short, assigns as the source of radiant energy, as light for example, electric disturbances in the body, rather than elastic vibrations of the atoms or molecules of the body.

599.

TABLES

DENSITIES

Air, at 0° C. and 76 cm. pressure	0.00129	Iron, cast	7.40
Alcohol	0.80	Iron, wrought	7.86
Aluminum	2.67	Ivory	1.82
Antimony.	6.72	Lead	11.30
Beeswax	0.96	Magnesium	1.75
Bismuth	9.82	Marble	2.72
Brass	8.5	Mercury, at 0° C.	13.596
Charcoal	1.60	Milk	1.03
Coal 1.3 to	1.80	Nickel	8.9
Copper	8.9	Olive oil	0.92
Cork	0.24	Paraffin	0.90
Diamond	3.53	Platinum	21.50
Ether	0.74	Silver	10.56
German silver	8.43	Steel	7.82
Glass, crown	2.60	Sulphuric acid	1.84
Glass, flint	3.70	Sulphur	2.03
Glycerine	1.26	Sugar	1.59
Gold	19.30	Tin	7.29
Granite	2.70	Water, at 0° C.	0.999
Human body	0.89	Water, at 4° C.	1.00
Ice	0.92	Water, sea	1.03
		Zinc	7.00

600.

VALUES OF G

Boston, Mass.	980.38	Washington, D. C.	980.10
Ithaca, N. Y.	980.29	Cincinnati, O.	979.99
Chicago, Ill.	980.26	Charlottesville, Va.	979.92
Cleveland, O.	980.23	Denver, Col.	979.60
Philadelphia, Pa.	980.18	Pike's Peak, Col.	978.94

601.

MELTING POINTS

Mercury	-38.8°	Aluminum	657°
Phosphorus	44.3	Silver	961
Sulphur	115	Gold	1063
Tin	232	Copper	1084
Bismuth	260	Iron	1100
Cadmium	320	Steel	1350
Lead	327	Platinum	1778
Zinc	419	Iridium	2200

602.

BOILING POINTS

Ethylene	- 103°	Alcohol	78°
Ammonia	- 38.5	Benzene	80
Chlorine	- 33.6	Toluene	110
Ether	35	Turpentine	160
Carbon bisulphid	46	Glycerine	290
Chloroform	61	Mercury	357

603. BOILING POINTS OF WATER UNDER DIFFERENT PRESSURES

73	98.88°	76	100.00°
74	99.26	77	100.37
75	99.63	78	100.73

604. EXTREMELY LOW FREEZING AND BOILING POINTS

	Freezing Point	Boiling Point
Ethylene	- 103°	
Helium	- 268.8	
Hydrogen	- 260°	- 252.5
Nitrogen	- 210	- 194
Oxygen	- 227	- 181

605.

SPECIFIC HEATS

Water	1.000	Aluminum	0.214
Ice	0.505	Glass	0.200
Ether	0.547	Iron	0.116
Alcohol	0.602	Copper	0.094
Tin	0.055	Mercury	0.033
Gold	0.032	Lead	0.031
Platinum	0.032	Zinc	0.094

606. NUMBER OF GRAMS OF WATER VAPOR REQUIRED TO SATURATE THE AIR, PER CUBIC METER

- 10° C.	2.363 g.	0° C.	4.835 g.	10° C.	9.330 g.
- 9	2.546	1	5.176	11	9.935
- 8	2.741	2	5.538	12	10.574
- 7	2.949	3	5.922	13	11.249
- 6	3.171	4	6.330	14	11.961
- 5	3.407	5	6.761	15	12.712
- 4	3.659	6	7.219	16	13.505
- 3	3.926	7	7.703	17	14.339
- 2	4.211	8	8.215	18	15.218
- 1	4.513	9	8.757	19	16.144

20° C.	17.118 g.	25° C.	22.796 g.	30° C.	30.039 g.
21 	18.143	26 	24.109	31 	31.704
22 	19.222	27 	25.487	32 	33.449
23 	20.355	28 	26.933	33 	35.275
24 	21.546	29 	28.450	34 	37.187

607. HEATS OF COMBUSTION IN CALORIES PER GRAM

Hydrogen	34700	Alcohol	7183
Gunpowder	700	Illuminating gas	6000
Dynamite	1300	Wood	about 4300
Sulphur	2200	Anthracite coal	8000

608. HEATS OF COMBUSTION IN B. T. U. PER POUND

<i>Bituminous Coal</i>		<i>Semi-Bituminous Coal</i>	
Streator, Ill.	13,700	Blossburg, Pa.	13,500
Wilmington, Ill.	14,000	Pocahontas, W. Va.	15,700
Saginaw, Mich.	13,500	Cumberland, Md.	16,300
Hocking Valley, O.	14,000		
Jackson, O.	14,000	<i>Anthracite Coal</i>	
Turtle Creek, Pa.	15,000	Lackawanna	13,900
Youghiogeny, Pa.	15,000	Lykens Valley	13,700
Thacker, W. Va.	15,200	Seranton	13,800

609. INDICES OF REFRACTION

Water	1.33	Benzene	1.50
Carbon bisulphide	1.64	Crown glass	1.52
Turpentine	1.47	Flint glass	1.62
Alcohol	1.36	Diamond	2.47

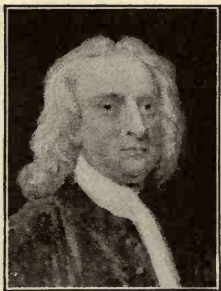
610. CONVERSION TABLES

<i>English to Metric</i>		<i>Metric to English</i>	
1 mile =	1.60935 km.	1 kilometer =	0.62137 mi.
1 mile =	1609.347 m.	1 meter =	0.0006214 mi.
1 foot =	0.3048 m.	1 meter =	3.28083 ft.
1 inch =	2.54 cm.	1 centimeter =	0.3937 in.
1 cubic foot =	28.31701 l.	1 liter =	0.03532 cu. ft.
1 gallon =	3.78543 l.	1 liter =	0.26417 gal.
1 pound =	0.45359 kg.	1 kilogram =	2.2046 lb.
1 grain =	0.064800 g.	1 gram =	15.432 gr.

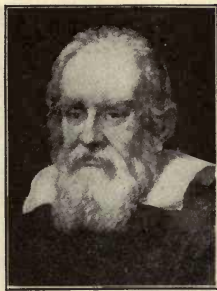
611.

WIRE GAUGE VALUES, AMERICAN (B. & S.)

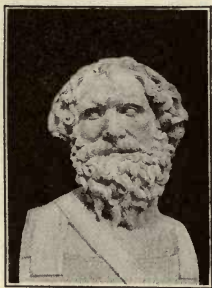
Gauge no.	Diam. in mm.	Diam. in Mils	Sq. of Diam. Mils	Gauge no.	Diam. in mm.	Diam. in Mils	Sq. of Diam. Mils
0000	11.684	460.00	211600.0	19	.899	35.39	1252.4
000	10.405	409.64	167805.0	20	.812	31.96	1021.5
00	9.266	364.80	133079.4	21	.723	28.46	810.1
0	8.254	324.95	105592.5	22	.644	25.35	642.7
1	7.348	289.30	83694.2	23	.573	22.57	509.5
2	6.544	257.63	66373.0	24	.511	20.10	404.0
3	5.827	229.42	52634.0	25	.455	17.90	320.4
4	5.189	204.31	41742.0	26	.405	15.94	254.0
5	4.621	181.94	33102.0	27	.361	14.19	201.5
6	4.115	162.02	26250.5	28	.321	12.64	159.8
7	3.665	144.28	20816.0	29	.286	11.26	126.7
8	3.264	128.49	16509.0	30	.255	10.03	100.5
9	2.907	114.43	13094.0	31	.227	8.93	79.7
10	2.588	101.89	10381.0	32	.202	7.95	63.2
11	2.305	90.74	8234.0	33	.180	7.08	50.1
12	2.053	80.81	6529.9	34	.160	6.30	39.7
13	1.828	71.96	5178.4	35	.143	5.61	31.5
14	1.628	64.01	4106.8	36	.127	5.00	25.0
15	1.450	57.07	3256.7	37	.113	4.45	19.8
16	1.291	50.82	2582.9	38	.101	3.96	15.7
17	1.150	45.26	2048.2	39	.090	3.53	12.5
18	1.024	40.30	1624.3	40	.080	3.14	9.9



Sir Isaac Newton (1642–1727), great English mathematician and physicist. Discovered the laws of gravitation, and announced laws of motion.



Galileo (1566–1642), Italian. Investigated the laws of falling bodies by dropping weights from the leaning tower of Pisa. Invented the telescope.



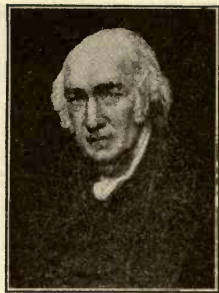
Archimedes (287–212 B.C.), Syracuse, Sicily. Discovered the laws of the lever, and the principle of buoyancy known as the Principle of Archimedes.



Lord Kelvin (Sir William Thomson), (1824–1907), born Belfast, Ireland. Professor of physics, University of Glasgow. Great mathematical physicist.



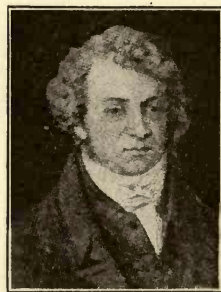
James Prescott Joule (1818–1889), English scientist. Determined the mechanical equivalent of heat.



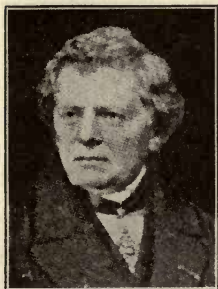
James Watt (1736–1819), Scotch instrument maker. Inventor of the modern type of steam engine.



Alessandro Volta (1748–1827), Italian physicist. Early investigator of current electricity. Voltaic cell and volt were named in his honor.



André Marie Ampère (1775–1836), French physicist. Investigated magnetic effects of currents. The ampere, unit of current strength, given his name.



Georg Simon Ohm (1789–1854), German scientist. Announced the electrical law named in his honor (Ohm's law).



Michael Faraday (1791–1867), English physicist and investigator in electricity and magnetism. Called the "prince of experimenters."



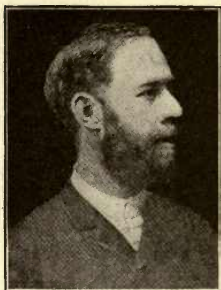
Sir William Crookes, English scientist, born 1832. Investigated the nature of matter in highly exhausted tubes, now known as Crookes' tubes.



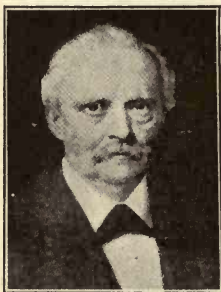
Wilhelm Konrad Roentgen, German scientific investigator, born 1845. Discovered X-rays, also called Roentgen rays.



James Clerk-Maxwell (1831–1879), professor of physics, University of Cambridge, England. Announced the famous electromagnetic theory of light.



Heinrich Rudolph Hertz (1857–1894), German physicist. Discoverer of electromagnetic waves predicted by Maxwell's theory.



Hermann von Helmholtz (1821–1894), one of the greatest German physicists and mathematicians of his day.



Madame Curie, born in Warsaw, Poland, 1867. Joint discoverer with her husband, Prof. Curie of the University of Paris, of the element radium.

PROBLEMS

MECHANICS

1. A body starting from rest is acted upon by a constant force which imparts to it an increase in velocity of 5 ft. per second each second. (a) Find its velocity in 10 seconds. (b) How far will it travel during the last 5 seconds?

2. A train coming into a station has at a given instant a velocity of 10 ft. per second. Five seconds later it has come to rest. (a) What was the negative acceleration? (b) How far did it move during the 5 seconds?

3. A body falls freely a distance of 1000 ft. Find its velocity (a) in feet; (b) meters.

4. A car starts from rest and in 10 seconds its velocity is 20 ft. per second. Find (a) its acceleration; (b) the distance it travels during the 10 seconds.

5. A body is thrown vertically downward from a cliff 800 ft. in height, with a velocity of 10 ft. per second. In what time will it reach the ground?

6. An electric car is running at the rate of 30 miles per hour. The brakes are applied and the car is stopped in 30 seconds. Find (a) the negative acceleration; (b) the distance the car moved after the brakes were applied.

7. How long will it take a force of 10 dynes acting on a mass of 100 grams to change its velocity from 5 to 25 cm. per second?

8. A stone thrown into the air reaches the ground in 5 seconds. Find (a) the height to which it ascended; (b) the velocity with which it struck the ground.

9. A ball having accelerated motion moves 10 ft. the first second and 15 ft. the second. Find (a) its velocity at the end of the third second; (b) the space it passes over during the third second.

10. A body is dropped from the top of a tower 300 ft. in height. At the same instant another body is projected vertically upward with a velocity of 300 ft. per second. Find at what point above the ground the two will pass each other.

11. A flag is hoisted to the masthead of a vessel a distance of 50 ft., during which time the vessel moves forward 100 ft. Find the magnitude and direction of the actual velocity of the flag.

12. A man riding on an electric car, which is running at the rate of 10 miles per hour, throws off a package at right angles to the track with a velocity of 10 ft. per second. Find the magnitude and direction of the velocity of the package.

13. Resolve a force of 100 lbs. into two components acting at an angle of 60° with each other.

14. The wind is blowing northeast with a velocity of 20 miles per hour. Resolve this velocity into two components, one to the northward and one to the eastward.

15. A weight of 100 lbs. is supported by two ropes fastened to a beam, each rope making an angle of 30° with the beam. Find the force exerted on each rope.

16. Find the length of a pendulum that makes 90 vibrations per minute, giving the result in (a) meters; (b) feet.

17. A weight attached to a string is suspended from an upper story of a building. The weight swinging as a pendulum just clears the ground. It makes 10 vibrations per minute. Find the length of the string.

18. An ounce bullet is shot from a 9 lb. gun with a velocity of 1000 ft. per second. Find the velocity of the gun's recoil.

19. A boy throws a stone weighing 8 oz. with a velocity of 20 ft. per second. Compare the momentum of the stone with that of a freight car weighing 20 tons and moving with a velocity of 8 miles per hour.

20. A body having a mass of 20 grams moves with a velocity of 2 meters per second. Find its kinetic energy in (a) kilogram meters; (b) gram centimeters; (c) ergs.

21. A 100 ton engine is moving with a velocity of 20 miles per hour. Find its kinetic energy in foot pounds.

22. A body having a mass of 10 lbs. falls vertically for 10 seconds. Find its kinetic energy in (a) foot poundals; (b) foot pounds.

23. A force of 10 lbs. acts for 10 seconds on a mass of 10 lbs. Find (a) the velocity at the end of the 10 seconds; (b) the energy in foot pounds.

24. A mass of 2 lbs. is attached to the rim of a wheel having a radius of 2 ft. The wheel rotates at the rate of 120 times a minute. Find the centrifugal force exerted by the body.

25. Find the horse power of an engine that can raise 10 tons to a height of 10 feet in 10 minutes.

26. A windmill pumps 5 tons of water from a well 50 ft. deep in 10 minutes. Find its horse power.

27. It is estimated that 700 tons of water passes over Niagara Falls per minute. The distance which it falls is 160 ft. Compute the horse power of Niagara Falls.

28. The wind drives a boat at the rate of 10 miles an hour against an

average resistance of 500 lbs. Compute the horse power furnished by the wind.

29. A force of 50 lbs. is applied to one end of a 10 ft. lever of the second class. A weight to be lifted is placed 2 ft. from the other end of the lever. What resistance will the force overcome?

30. A uniform bar 10 ft. in length and weighing 2 lbs. to the foot is used as a lever of the first class. The fulcrum is placed 2 ft. from the end. Taking into account the weight of the lever, what force will be required at one end to overcome a resistance of 800 lbs. at the other?

31. A given bicycle wheel is 28 inches in diameter. The driving sprocket is 8 inches in diameter, the small sprocket 2 inches. How many times will the rider have to move his feet up and down in going a mile?

32. The axle of a windlass is 4 inches in diameter; the crank by which the windlass is turned is x inches. A force of 10 lbs. applied to the end of the crank supports 100 lbs. on the rope passing around the axle. Find the value of x .

33. The pilot wheel on a boat is 4 ft. in diameter; the axle 6 inches in diameter. What force must the pilot apply to the wheel in order to steer the boat, assuming that the steering resistance against the motion of the wheel is 300 lbs.?

34. A weight of 2 tons is to be raised by a jackscrew, the lever of which is 3 ft. long. What force must be applied, assuming that the screw threads are 2 to the inch?

35. Show by diagram how you would arrange 3 pulleys so as to lift the greatest weight.

36. The diameter of a wheel of a copying press is 14 inches. On the screw there are 5 threads to the inch. If the wheel be turned with a force of 20 lbs. applied to its outer rim, what will be the downward thrust exerted by the screw?

37. A cubical tank 4 ft. wide, 6 ft. deep, and 10 ft. long is filled with water. Find (a) the force exerted on the bottom; (b) on one end.

38. Over the top of the tank of problem 37 there is fitted a tight cover, into the surface of which there is inserted a plug having a cross sectional area of 10 sq. in. A force of 10 lbs. is applied to the plug. Find the force transmitted to one side of the tank due to the force on the plug.

39. A hydraulic elevator is operated by water from the city mains under a pressure of 70 lbs. per sq. in. The cross sectional area of the piston is 70 sq. in. What load can be lifted due to the water pressure?

40. The diameter of the small piston of a hydraulic press is 2 inches; that of the large piston, 2 ft. A weight of 100 lbs. applied to the small piston will exert what upward force on the large piston?

41. The weight of a piece of lead is 1 kg.; the density of lead is 11.3. Find the volume of the piece of lead.
42. The 100-gram weight of a set of weights is made of brass, the density of which is 8.4. Find the volume in cc. of the 100-gram weight.
43. Determine, by reference to the density tables, the volume of a vessel which holds 1 kg. of ether.
44. The dimensions of a brick are $8 \times 4 \times 2$ inches; its weight 4 lbs. Find its density.
45. If you were offered a cubic foot of gold provided you could carry it, with the understanding that you were to forfeit \$10 in case you could not lift it, would you accept the offer?
46. An ice box is $3 \times 2 \times 1$ ft. When it is filled with ice, about how many pounds does it hold, assuming that the density of ice is 0.9?
47. Compute the mass of the earth in tons, assuming its radius to be 4000 miles and its average density 5.5.
48. The difference between the barometric reading at the bottom and the top of the Eiffel Tower, Paris, which is 1000 ft. in height, is 1.1 inch. Compute the normal barometric reading at Denver, which is 5400 ft. above sea level.
49. As a balloon rises will the fall of the barometer be proportional to the distance passed over? Why?
50. Over what height may water be siphoned on a mountain 1 mile above sea level, assuming that an ascent of 90 ft. is equivalent to a fall in the barometric column of 0.1 inch.?
51. Consult the density tables and compute the approximate weight of the air in a room $10 \times 20 \times 30$ ft.
52. Into what space must 30 cu. ft. of air be compressed in order that its density be increased threefold?

HEAT

53. Reduce -10° , $+10^\circ$, $+41^\circ$, $+68^\circ$, $+180^\circ$ F. to the C. scale.
54. Mercury boils at $+357^\circ$ C. Find its boiling point on the F. scale.
55. Ordinary room temperature is 70° F. What is this on the C. scale?
56. How much must an iron rod 40 ft. long be heated to expand 1 inch, the coefficient of linear expansion of iron being 0.000012?
57. The temperature of liquid air is -181° C. Express this temperature on the F. scale.
58. How much will an iron telegraph wire 1000 ft. in length contract if the temperature falls 20° C.?
59. How many grams of boiling water at 100° C. must be added to 5

liters of cold water at 5°C . in order that the resulting temperature be 25°C ?

60. How much mercury at 100°C . must be added to 100 grams of water at 10°C . in order that the resulting temperature of the mixture be 20°C .?

61. One kilogram of ice is melted and the temperature of the water is raised to the boiling point. How many calories of heat are required?

62. Ten pounds of ice are melted and the temperature of the water raised to the boiling point. Find the number of B.T.U. required.

63. A copper vessel having a mass of 100 grams contains 300 grams of water at 100°C . How many grams of ice at 0°C . must be put into the water in order to lower the temperature to 50°C .?

64. One hundred grams of steam at 100°C . are changed to ice at 0°C . How many calories of heat are given out?

65. One hundred grams of ice at -10°C . are changed to steam at 100°C . How many calories of heat are required, assuming the specific heat of ice to be 0.5?

66. A certain mass of gas at 20°C . has a volume of 1 liter. Find its volume at -10°C ., the pressure remaining constant.

ELECTRICITY AND MAGNETISM

67. A wire 10 ft. long has a diameter of 1 mm. What must be the diameter of a second wire 20 ft. long in order to offer half the resistance of the first?

68. If the resistance of a given wire 10 m. long and 2 mm. in diameter be 10 ohms, what length of wire of the same material 1 mm. in diameter will be required to give a resistance of 5 ohms?

69. The diameter of a copper wire 10 ft. in length is 0.025 inches. Find by reference to Table of Constants (a) its diameter in mils; (b) its resistance in ohms.

70. Three wires whose resistances are 5, 6, and 7 ohms respectively are joined in parallel. Find the resistance of the three wires thus connected.

71. What E.M.F. is necessary to maintain a current of 0.5 ampere through a resistance of 70 ohms?

72. A battery of 5 cells is connected in series with an external resistance of 50 ohms. The E.M.F. of each cell is 1.5 volts and its internal resistance 1 ohm. What current does the battery furnish?

73. The E.M.F. of a battery is 10 volts and the strength of current which it maintains through a resistance of 10 ohms is 0.5 ampere. Find the internal resistance of the battery.

74. An electromagnet of 10 ohms resistance and a rheostat of 20 ohms

resistance are connected in series. A current of 0.5 amperes flows through the circuit. Find the fall of potential over each instrument.

75. A difference of potential of 10 volts is applied to the terminals of a telegraph relay, giving rise to a current of 0.1 ampere. Find the resistance of the relay.

76. An arc lamp under a pressure of 50 volts runs on a current of 5 amperes. Find (a) the power expended in kilowatts; (b) the cost of running this lamp for 5 hours at 10 cents per kilowatt hour.

77. A conductor having a resistance of 10 ohms carries a current of 5 amperes. How much energy is consumed in 10 minutes in (a) calories? (b) ergs?

78. How much heat is developed per hour by a 55 watt incandescent lamp on a 110 volt circuit?

79. A current of 5 amperes at a pressure of 110 volts passes through the primary of an induction coil, having 200 turns of wire in the primary and 2000 in the secondary. What will be the strength of the induced current in the secondary, assuming that there are no losses?

80. An induction coil has 200 turns in its primary and 60,000 in its secondary. A pressure of 10 volts is applied to the primary. What voltage will be induced in the secondary?

81. A transformer is used to step an alternating current having a pressure of 1000 volts down to one of 50 volts. If there are 500 turns of wire in the primary, how many will there be in the secondary?

SOUND

82. A bullet fired with a velocity of 1200 ft. per second is heard to strike a target 5 seconds after leaving the rifle. Find the distance of the target, the temperature being 20°C .

83. The Eiffel Tower is 1000 ft. high. A bell is struck at the top. In what time will the sound reach a point 1000 ft. from the center of the base, the temperature being 68°F .?

84. A given tuning fork makes 300 vibrations per second. What effect will a rise of 20°C . have upon the wave length produced by this fork?

85. On a day when the temperature is 77°F . a report of a rifle is heard 5 seconds after the puff of smoke is seen. How far away is the rifle?

86. A wave length of the sound wave given out by an organ pipe is 5 meters when the temperature is 20°C . Find the vibration number of the pipe.

87. Two strings on a piano give 3 beats per second. If the vibration number of one of the strings is 320, what is that of the other?

88. A closed organ pipe produces waves 6 ft. in length. (a) What is the length of the pipe? (b) What is the length of an open pipe that will produce waves of the same length?

89. A given string stretched by a force of 16 lbs. makes 256 vibrations per second. What will be the vibration rate if the stretching force be increased to 25 lbs.?

90. A string 1 meter long makes 512 vibrations per second. What will be the frequency of the string if its length be decreased by 25 cm.?

LIGHT

91. The page of a book is held 1 ft. from a given light. It is then removed to a distance of 5 ft. Compare the intensities of light on the page in the two cases.

92. A gas flame placed 6 ft. from the screen of a Bunsen photometer illuminates it as much as a standard candle placed at a distance of 6 inches. What is the candle power of the gas flame?

93. It is estimated that the nearest fixed star is 25,000,000,000,000 miles from the earth. Find the time required for light to travel from this star to the earth.

94. Two planes are placed at a distance of 2 ft. and 3 ft. respectively from a given source of light. What must be the relative area of the two planes in order that they intercept the same amount of light?

95. The radius of curvature of a concave mirror is 30 cm. An object is placed at a distance of 50 cm. from the vertex of the mirror. (a) Find the distance of the image from the mirror. (b) Will it be real or virtual?

96. A candle placed 20 cm. from the vertex of a concave mirror gives a real image 50 cm. from the mirror. Find (a) the focal length of the mirror; (b) its radius of curvature.

97. Light travels in a given liquid with a velocity of 136,000 miles per second. Find the index of refraction of this liquid.

98. An object is placed 70 inches in front of a convex lens, the focal length of which is 4 inches. (a) Find the distance of the image from the lens. (b) What will be its size as compared with that of the object?

99. A convex lens, the focal length of which is 2 ft., is placed 14 ft. from a screen. (a) Where must a candle be placed in order that its image be focused upon the screen? (b) What will be the size of the image as compared with that of the candle?

100. A convex lens having a focal length of 3 cm. is held 2.7 cm. from an object. (a) How far will the image be from the lens? (b) Will it be real or virtual?

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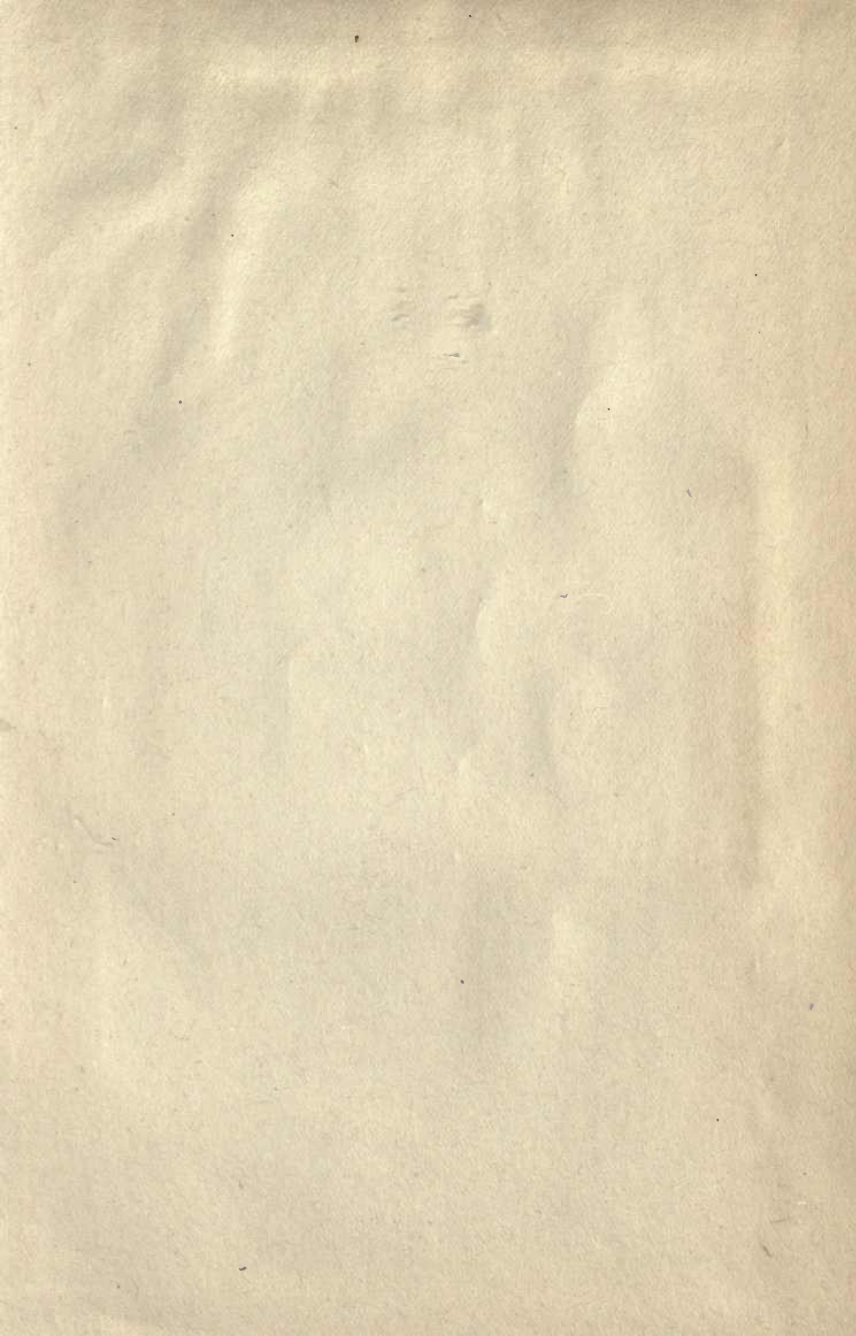
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